IUCAA

37th

ANNUAL REPORT
2024-25

अंतर–विश्वविद्यालय केंद्र : खगोलविज्ञान और खगोलभौतिकी

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

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INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

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Sakya Sinha
Saravanan T.R.
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54. Mamta Dahiya, Department of Physics and Electronics, SGTB Khalsa College, Delhi.
55. Himadri S. Das, Department of Physics, Assam University, Silchar.
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57. Shyam Das, Department of Physics, Malda College, Malda.
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101. Rinku Jacob, Department of Basic Sciences and Humanities, Rajagiri School of Engineering and Technology, Kakkanad, Kochi, Kerala.
102. Chetana Jain, Department of Physics, Hansraj College, Delhi.
103. Deepak Jain, Department of Physics, Deen Dayal Upadhyaya College, New

Delhi.

104. Rajeev K. Jain, Department of Physics, IISc, Bangalore.
105. Nur Jaman, Dhruba Chand Halder College, 24 Parganas, West Bengal.
106. Charles Jose, Department of Physics, Cochin University of Science and Technology, Kochi, Kerala.
107. Jessy Jose, Department of Physics, IISER, Tirupati.
108. Chandan Joshi, JECRC University, Jaipur, Rajasthan.
109. Minu Joy, Department of Physics, Alphonsa College, Pala, Kerala.
110. Jeena K., Department of Physics, Providence Women's College, Kozhikode, Kerala.
111. Sathya Narayanan K., Department of Physics, The Cochin College, Kochi, Kerala.
112. Md. Mehedi Kalam, Department of Physics, Aliah University, Kolkata.
113. Sanjeev Kalita, Department of Physics, Gauhati University, Guwahati.
114. Nagaraja Kamsali, Department of Physics, Bangalore University, Bangalore.
115. Pralay Kumar Karmakar, Department of Physics, Tezpur University, Assam.
116. Sreeja S Kartha, Department of Physics & Electronics, Christ (Deemed to be University) Bangalore, Karnataka.
117. Pradeep Kumar Kayshap, VIT Bhopal University, Bhopal.
118. Arun Kenath, Department of Physics & Electronics, Christ (Deemed to be University), Bangalore.
119. Nishikanta Khandai, School of Physical Sciences, NISER, Bhubaneswar.
120. Ram Kishor, Department of Mathematics, Central University of Rajasthan, Ajmer.
121. Newton Singh Kshetrimayum, Department of Physics, National Defence Academy, Khadakwasla, Pune.
122. Arun V. Kulkarni, Department of Physics, BITS - Pilani, Goa.
123. Bharat Kumar, Department of Physics & Astronomy, NIT, Rourkela, Orissa.
124. Nagendra Kumar, Department of Mathematics, MMH College, Ghaziabad.
125. Rajesh Kumar, Department of Mathematics and Statistics, DDU Gorakhpur University, Uttar Pradesh.
126. R.K. Sunil Kumar, Department of Information Technology, Kannur University, Kerala.
127. Sanjay Kumar, PG Department of Physics, Patna University, Patna.
128. Subhash Kumar, Department of Physics, Acharya Narendra Dev College (University of Delhi), Delhi
129. Suresh Kumar, Department of Mathematics, Plaksha University, Punjab.
130. Richa Kundu, Department of Physics, University of Delhi, Delhi.
131. Badam Singh Kushvah, Indian Institute of Technology, Indian School of Mines Dhanbad, Jharkhand.
132. Upendra Kumar Singh Kushwaha, Department of Physics, University of Allahabad, Uttar Pradesh.
133. Haris M K, Department of Physics, NIT Calicut, Kerala.
134. Vinjanampaty Madhurima, Department of Physics, Central University of Tamil Nadu, Thiruvarur.
135. Smriti Mahajan, Department of Physics, IISER, Mohali.
136. Liton Majumdar, Department of Physics, NISER, Bhubaneswar.
137. Shiva K. Malapaka, Department of Physics, IIIT, Bengaluru.
138. Manzoor A. Malik, Department of Physics, University of Kashmir, Srinagar.
139. Soma Mandal, Department of Physics, Government Girls' General Degree College, Kolkata.
140. Tuhina Manna, St. Xaviers College (Autonomous), Kolkata, West Bengal.
141. Titus K. Mathew, Department of Physics, Cochin University of Science and Technology, Kochi, Kerala.
142. Ram A. Maurya, Department of Physics, NIT Calicut, Kozhikode, Kerala.
143. Biman J. Medhi, Department of Physics, Gauhati University, Guwahati.
144. Poonam Mehta, School of Physical Sciences, Jawaharlal Nehru University, New Delhi.
145. Irom A. Meitei, Department of Physics, Manipur University, Imphal.
146. Manesh Michael, Department of Physics, Bharata Mata College, Kochi, Kerala.
147. Hameeda Mir, Department of Physics, Government Degree College, Srinagar.
148. Mubashir H. Mir, Department of Physics, Government Degree College, Bandipora, Jammu and Kashmir.
149. Bivudutta Mishra, Department of Mathematics, BITS - Pilani, Hyderabad.
150. Sourav Mitra, Department of Physics, Surendranath College, Kolkata.
151. Sajahan Molla, Department of Physics, New Alipore College, Kolkata.
152. Aditya S. Mondal, Department of Physics, Visva-Bharati University, Santiniketan.
153. Saptarshi Mondal, Department of Physics, Bethune College, Kolkata.
154. Soumen Mondal, Department of Physics, Jadavpur University, Kolkata.
155. Rupak Mukherjee, Sikkim University, Gangtok, Sikkim.
156. Sajal Mukherjee BITS-Pilani Campus, Rajasthan.
157. Mahadevappa Naganathappa, Gitam (Deemed to be University) Hyderabad Campus, Telangana.
158. Hemwati Nandan, Department of Physics, HNB Garhwal University, Uttarakhand.
159. Dibyendu Nandi, IISER, Kolkata.
160. Rajesh K. Nayak, Department of Physical Sciences, IISER, Kolkata.

161. Rahul Nigam, BITS Hyderabad, Telangana.
162. Chandrachani Devi Ningombam, Physics Department, Manipur University, West Manipur.
163. Prince P. R., Department of Physics, University College, Thiruvananthapuram.
164. Sreejith Padinhatteeri, Manipal Centre For Natural Sciences, Manipal Academy of Higher Education, Udupi, Karnataka.
165. Barun K. Pal, Department of Physics, Netaji Nagar College for Women, Kolkata.
166. Dr. Main Pal, Sri Venkateswara, College University of Delhi, Delhi.
167. Dr. Sabyasachi Pal, Midnapore City College Vidyasagar University Midnapore, West Bengal.
168. Kanik Palodhi, Department of Applied Optics, University of Calcutta, Kolkata.
169. Biswajit Pandey, Department of Physics, Visva-Bharati University, Santiniketan.
170. Sanjay K. Pandey, Department of Mathematics, L.B.S. Degree College, Gonda, Uttar Pradesh.
171. Mahadev B. Pandge, Department of Physics, Dayanand Science College, Latur, Maharashtra.
172. Uma Papnoi, Department of Physics, Government PG College, Uttarakhand.
173. Rutu M. Parekh, Dhirubhai Ambani Institute of Information & Communication Technology, Gandhinagar, Gujarat.
174. Abhishek Paswan, Department of Physics, University of Allahabad, Prayagraj, Uttar Pradesh.
175. Amit Pathak, Department of Physics, Banaras Hindu University, Varanasi.
176. Prashant Pathak, IIT Kanpur, Uttar Pradesh.
177. Kishor D. Patil, Dnyan Bharti College, Deoli Wardha.
178. Madhav K. Patil, School of Physical Sciences, Swami Ramanand Teerth Marathwada University, Nanded, Maharashtra.
179. Bikash C. Paul, Department of Physics, University of North Bengal, Siliguri.
180. Surajit Paul, Manipal Center for Natural Sciences, Manipal Academy of Higher Education, Manipal, Karnataka.
181. Devraj D. Pawar, Department of Physics, RJ College, Mumbai.
182. Ninan S. Philip, Artificial Intelligence Research and Intelligent Systems, Thelliyoor, Kerala.
183. Ananta C. Pradhan, Department of Physics and Astronomy, NIT, Rourkela.
184. Anirudh Pradhan, Department of Mathematics, GLA University, Mathura.
185. Ram Prasad Prajapati, School of Physical Sciences, Jawaharlal Nehru University, New Delhi.
186. Dr. Raj Prince, Department of Physics, Institute of Science, Banaras Hindu University, Varanasi, Uttar Pradesh.
187. Anisur Rahaman, Durgapur Government College, Durgapur, West Burdwan.
188. Farook Rahaman, Department of Mathematics, Jadavpur University, Kolkata.
189. Nisha Rani, Miranda House University of Delhi, Delhi.
190. Rakhi R., Department of Physics, N. S. S. College, Pandalam, Kerala.
191. Rajesh S.R., Department of Physics, Sanatana Dharma College, Alappuzha, Kerala.
192. Chayan Ranjit, Department of Mathematics, Egra S.S.B. College, Purba, Medinipur, West Bengal.
193. Shantanu Rastogi. Department of Physics, D.D.U. Gorakhpur University, Gorakhpur.
194. Aasheesh Raturi, Dolphin PG Institute of Biomedical and Natural Sciences, Dehradun, Uttarakhand.
195. C.D. Ravikumar, Department of Physics, University of Calicut, Kozhikode, Kerala.
196. Saibal Ray, Centre for Cosmology, Astrophysics & Space Science (CCASS) GLA University Mathura, Uttar Pradesh.
197. Biplab Raychaudhuri, Department of Physics, Visva-Bharati University, Santiniketan.
198. Pramit Rej, Department of Mathematics, Sarat Centenary College, Hooghly, West Bengal.
199. Rupak Roy, Manipal Center for Natural Sciences, Manipal Academy of Higher Education, Manipal, Karnataka.
200. Prabir Rudra, Department of Mathematics, Asutosh College, Kolkata.
201. Aswathy S., Department of Physics, Providence Women's College, Kozhikode, Kerala.
202. Sunil Kumar S., Department of Physics, IISER, Tirupati.
203. Dr. Sonali Sachdeva, Jaypee University Anousheh, Uttar Pradesh.
204. Anirban Saha, Department of Physics, West Bengal State University, Kolkata.
205. Sanjay K. Sahay, Department of Computer Science and Information Systems, BITS - Pilani, Goa.
206. Sandeep Sahijpal, Department of Physics, Panjab University, Chandigarh.
207. Pradyumn Kumar Sahoo, BITS-Pilani, Hyderabad Campus, Hyderabad, Telangana.
208. Eeshankur Saikia, Department of Applied Sciences, Gauhati University, Assam.
209. Gauranga C. Samanta, PG Department of Mathematics, Fakir Mohan University, Balasore, Orissa.
210. Prasant Samantray, Department of Physics, BITS - Pilani, Hyderabad.
211. Biplob Sarkar, Department of Applied Sciences, School of Engineering, Tezpur University, Tezpur.
212. Prakash Sarkar, Kashi Sahu College Seraikella Dist - Jharkhand.
213. Rathin Sarma, Department of Physics, Rabindranath Tagore University, Hojai.
214. Saumyadip Samui, Department of

Physics, Presidency University, Kolkata.

215. Subrata Sarangi, Department of Physics, Centurion University of Technology and Management, Bhubaneswar.
216. Tamal Sarkar, High Energy and Cosmic Ray Research Centre, University of North Bengal, Siliguri.
217. Anjan A. Sen, Centre for Theoretical Physics, Jamia Millia Islamia, Delhi.
218. Asoke K. Sen, Department of Physics, Assam University, Silchar, Assam.
219. Somasri Sen, Department of Physics, Jamia Millia Islamia, Delhi.
220. Anand Sengupta, Department of Physics, IIT, Gandhinagar, Gujarat.
221. T.R. Seshadri, Department of Physics and Astrophysics, University of Delhi, Delhi.
222. Kannabiran Seshasayanan, Department of Applied Mechanics and Biomedical Engineering Indian Institute of Technology Chennai.
223. Geetanjali Sethi, Department of Physics, St. Stephens College, University of Delhi, Delhi.
224. Mohd Shahalam, Integral University, Lucknow.
225. Aishawnnya Sharma, Department of Physics, Bahona College, Jorhat.
226. Kaushal Sharma, Regional Forensic Science Laboratory, Uttar Pradesh.
227. Dr. Prerana Sharma, Government Ujjain Engineering College, Ujjain, Madhya Pradesh.
228. Ranjan Sharma, Department of Physics, Cooch Behar Panchanan Barma University, West Bengal.
229. Umesh K. Sharma, Department of Mathematics, GLA University, Mathura.
230. Md. Salim Md. Harun Shekh, S. P. M. Science and Gilani Arts Commerce College, Yavatmal.
231. Amit Shukla, Discipline of Astronomy, Astrophysics and Space Engineering, IIT, Indore.
232. Ashutosh Singh, Centre for Cosmology, Astrophysics and Space Science GLA University Mathura, Uttar Pradesh.
233. Alkendra Singh, Department of Physics, Institute of Science, Banaras Hindu University, Varanasi.
234. Dharm Veer Singh, Department of Physics, GLA University Mathura, Uttar Pradesh.
235. Gyan P. Singh, Department of Mathematics, Visvesvaraya National Institute of Technology, Nagpur.
236. Harinder P. Singh, Department of Physics and Astrophysics, University of Delhi, Delhi.
237. Heisnam S. Singh, Department of Physics, Rajiv Gandhi University, Arunachal Pradesh.
238. Suprit Singh, Department of Physics, Indian Institute of Technology, New Delhi.
239. Monika Sinha, Department of Physics, IIT, Jodhpur.
240. Surendra N. Somala, Department of Civil Engineering, IIT, Hyderabad.
241. Sourav Sur, Department of Physics &Astrophysics, University of Delhi (North Campus), New Delhi.
242. Mayuresh Prakash Surnis, IISER, Bhopal, Madhya Pradesh.
243. Shabnam Iyyani Syamsunder, School of Physics, IISER, Thiruvananthapuram, Kerala.
244. Parijat Thakur, Department of Basic Sciences and Humanities, Guru Ghasidas Central University, Bilaspur.
245. Arun V. Thampan, Department of Physics, St. Joseph's University, Bangalore.
246. Vivek Baruah Thapa, Department of Physics, Bhawanipur Anchalik College, Assam.
247. Vithal P. S. Tilvi, Department of Physics, Government College of Arts, Science and Commerce, Khandola, Goa.
248. Ajay Tripathi, Department of Physics, Sikkim University, Gangtok, Sikkim.
249. Sunil K. Tripathy, Department of Physics, Indira Gandhi Institute of Technology, Orissa.
250. Vinutha Tummala, Department of Applied Mathematics, Andhra University, Visakhapatnam.
251. Rashmi Uniyal, Department of Physics, Government Degree College, Narendranagar, Uttarakhand.
252. Sanil Unnikrishnan, Department of Physics, St. Stephen's College, Delhi.
253. Sudhaker Upadhyay, Department of Physics, KLS College, Nawada, Bihar.
254. Anisul A. Usmani, Department of Physics, Aligarh Muslim University, Aligarh.
255. Jithesh V, Department of Physics and Electronics, Christ (Deemed To Be University) Bengaluru.
256. Nilkanth D. Vagshette, Department of Physics and Electronics, Maharashtra Udaygiri Mahavidyalaya, Udgir, Maharashtra.
257. Bhargav P. Vaidya, Discipline of Astronomy, Astrophysics and Space Engineering, IIT, Indore.
258. Murli M. Verma, Department of Physics, University of Lucknow, Lucknow.
259. Surender Verma, Department of Physics & Astronomical Science, Central University of Himachal Pradesh, Kangra, Himachal Pradesh.
260. Vinu Vikraman, Department of Physics, Central University of Kerala, Kerala.
261. Abhay Pratap Yadav, Department of Physics and Astronomy, NIT Rourkela, Odisha.
262. Jaswant K. Yadav, Department of Physics, Central University of Haryana, Haryana.
263. Nitin Yadav, Department of Physics, IISER Thiruvananthapuram, Kerala.
264. Lalthakimi Zadeng, Department of Physics, Mizoram University, Aizawl.

The Thirty-Fifth batch (2024) of Visiting Associates, who were selected for a tenure of three years, beginning August 1, 2024.

Md Sabir Ali

Soumya Chakrabarti

Samyaday Choudhury

Shubhrangshu Ghosh

Prabir Kumar Haldar

Syed Najamul Hasan

Gopal Hazra

Nur Jaman

Chanpdan Joshi

Haris M K

Subhash Kumar

Upendra Kumar Singh Kushwaha

Poonam Mehta

Rupak Mukherjee

Sajal Mukherjee

Dibyendu Nandi

Sabyasachi Pal

Kanik Palodhi

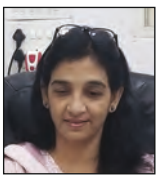
Prashant Pathak

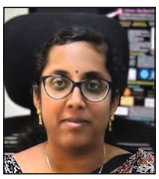
Raj Prince

Aasheesh Raturi

Sonali Sachdeva

Kaushal Sharma


Prerana Sharma


Shabnam Iyyani Syamsunder

Vivek Baruah Thapa

Ajay Tripathi

Surender Verma

Vinu Vikraman

Abhay Pratap Yadav

Appointment of the following visiting associates of the thirtieth batch was extended for 3 years from August 2024

Gazi Ameen Ahmed, Sampurn Anand, Indrani Banerjee, Shyamal Kumar Banerjee, Prasad Basu, Piyali Bhar, Bari Maqbool Bhat, Ritabrata Biswas, Debasish Borah, Koushik Chakraborty, Laxmikant Chaware, C.D. Ravikumar, Partha Sarathi Debnath, Shanti Priya Devarapalli, Anoubam Senorita Devi, Vijayakumar Honnappa Doddamani, Broja Gopal Dutta , Jibitesh Dutta, Sudip Kumar Garain , Suman Ghosh, Tuhin Ghosh, Sarbari Guha, Golam Mortuza Hossain, Joe Jacob, Rajeev Kumar Jain, Deepak Jain, Jessy Jose, Charles Jose, Minu Joy, Jeena K., Nishikanta Khandai, Mamta, Biman Jyoti Medhi, Sourav Mitra, Sajahan Molla, Soumen Mondal, Hemwati Nandan, Rajesh Kumble Nayak, Sanjay Kumar Pandey, Biswajit Pandey, Uma Papnoi, Amit Pathak, Bikash Chandra Paul, Bhargav Pradeep Vaidya, Ananta Charan Pradhan, Farook Rahaman, Chayan Ranjit, Reshma Sada Raut Dessai, Aswathy S., Sanjay Kumar Sahay, Sandeep Sahijpal, Prasant Samantray, Subrata Sarangi, Rathin Sarma, Asoke Kumar Sen, Somasri Sen, Priya Hasan, Aishawnnya Sharma, Ranjan Sharma, Amit Shukla, Alkendra Singh, Parijat Thakur, Vithal P. Shet Tilvi, Sanil Unnikrishnan, Sudhaker Upadhyay.

ORGANISATIONAL STRUCTURE OF IUCAA'S ACADEMIC PROGRAMMES

[As of March 31, 2025]

The Director

R. Srianand

Chairman (SCA, Infrastructural Facilities & SCCAP)

R. Srianand

Dean, Core Academic Programmes

A. N. Ramaprakash

Head, Computing Facilities

Sanjit Mitra

Head, Instrumentation & IGO

A.N. Ramaprakash

Head, Teaching Programmes

Aseem Paranjape

Head, Library

Kanak Saha

Head, Publications

Dipanjan Mukherjee

Head, Rajbhasha Committee

Vaidehi Paliya

Head,
Grievance Cell

Gulab C. Dewangan

Chairperson,
IUCAA Committee Against Sexual Harassment (ICASH)

Nirupama Bawdekar

Chairman,
Special Cell for Scheduled Cast and Scheduled Tribes

Nitin Ohol

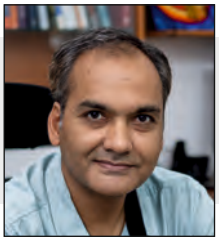
Dean,
Visitor Academic Programmes

Ranjeev Misra

Head,
Observing Programmes (IGO and SALT)

Gulab C. Dewangan

Head,
Scientific Meetings and ICARDs



Durgesh Tripathi

Head,
Public Outreach Programmes

Nishant Singh

DIRECTOR'S REPORT

The main objectives of IUCAA are to provide a centre of excellence within the university sector for teaching, research and development in Astronomy & Astrophysics (A&A), as well as to promote nucleation and growth of active groups in this area in the universities. The aim is to provide researchers from universities access to state-of-the-art astronomical instrumentation, theoretical know-how, well-equipped laboratories, a Data Centre and high-quality computing facilities. For more than three decades, IUCAA has not only achieved these objectives, but, has maintained the emphasis on fundamental research and innovative teaching in a wide range of areas of A&A. Over the period IUCAA's interactions with universities has also evolved as per the demands of the changing research and technology landscape in the country and abroad.

At present, IUCAA's academic staff consists of 24 faculty members (including Emeritus Professors), 4 Adjunct faculty members, 47 Ph.D. students, 20 Post-Doctoral Fellows, 41 Scientific and technical staff and five project students. The high level of science productivity of IUCAA's academic staff is reflected in the fact that during this academic year, they have published about 182 papers in peer-reviewed journals. The average impact factor for these publications is 5.61 Our M.Sc. Physics (Astrophysics) Programme in collaboration with SPPU-Physics Department continues to attract young students across the country, and we are happy to see that a good fraction of students graduating from this programme are taking up Ph.D. admissions in different astronomy institutions in the country and abroad. This year, we have initiated the setting up of an introductory-level laboratory for gravitational science. A first school for Masters students using this laboratory was planned for the winter months of 2024.

The number of IUCAA Associates also shows a steady increase over the period. Now the total number of Associates stands at 264. This year, we have re-established the Users Committee of IUCAA, and the first meeting of this Committee was held on September 25, 2024. The main objective of this Committee is to make recommendations to the Governing Board for optimal and effective utilisation of IUCAA's facilities by the visiting university scientists. It may, in general, comment on the Visitor Academic Programmes such as schools, courses, workshops, etc., conducted by IUCAA. This Committee also has the responsibility of devising methods for obtaining feedback from the users. The recommendations of this Committee after its first meeting includes (i) Setting up procedures for screening and evaluation of Associates, (ii) possible expansion of IUCAA Centre for Astronomy Research and Development (ICARD) activities that are aligned with various IUCAA activities, (iii) establishing 'working groups' based on different research themes, (iv) identify IUCAA faculty coordinator for different regions in the country, (v) establishing training labs for Masters students, (vi) setting up fellowship for Ph.D. thesis work that uses IUCAA supported facilities and (vii) establishing nation-wide summer internship programmes for students with the support of IUCAA Associates. We have already initiated steps to implement these recommendations.

This year, we have roughly doubled the number of ICARDs. There are 41 ICARDs across the country. These were established to contribute to the development of up-to-date

course structures and new kinds of experiment/data analysis sessions, which can be a part of a starting or existing Astronomy course in universities. Efforts are being made to have new ICARDs in regions that are not well represented at present. For the first time, ICARD activities are displayed during this year's National Science Day celebrations.

SARATHI, a powerful HPC facility at IUCAA, is dedicated to LIGO data analysis and is IUCAA's contribution to the International Gravitational Wave Observatory Network (IGWN). SARATHI accounts for about 15% of IGWN computing resources. The PEGASUS HPC cluster is a dedicated facility made available to the general users of IUCAA and researchers from Indian universities. We have enhanced the computing power of PEGASUS by 25%, and efforts are on to enhance the storage facilities. We have also established a usage policy document and set up a Time Allocation Committee and a usage monitoring committee to maximise the efficient usage of HPC. This year, we have gone through two cycles of time allocation for HPC-based projects. Each cycle, we received about 20 proposals with an over-subscription factor of 3. We are happy to note that 80% of these proposals (utilising about 36% of the allocated time) received are from the university researchers. Efforts are being made to conduct workshops to introduce our HPC to young university researchers so that our HPCs are utilised with higher efficiency.

The LIGO-India Project to construct the GW observatory in India is progressing very well. The project is being led by four lead institutions: The Directorate of Construction Services and Estate Management (DCSEM), Mumbai, the Institute of Plasma Research (IPR), Gandhinagar, the Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune and Raja Ramanna Centre for Advanced Technology (RRCAT), Indore. Major milestones achieved during this year include (i) establishing the management structure with details of sub-system leads and members of each sub-system team. (ii) establishing the mechanism to support flow of funds to different lead-institutions, (iii) establishing the financial powers of various stakeholders in the project, (iv) finalising the EPC tender for the construction of civil and mechanical infrastructure at the site, (v) preparing the white paper document listing various developmental projects that LIGO-India would like scientists across the country to engaged in. IUCAA is establishing a mechanism to initiate a call for proposals, selection, funding and monitoring of the white paper-based projects. We expect the first call to occur during the financial year. IUCAA continue to be involved in different Education and Public Outreach (EPO) Programmes focusing on gravitational wave science.

We are happy to note that the SUIT on board the ADITYA-L1 space telescope is performing well. IUCAA is hosting the Payload Operations Centre (POC) for the SUIT instrument. The first set of science papers has just been published by the SUIT team. Like past years, it is gratifying to note that the number of papers published using AstroSat data and the number of individual users of AstroSat continue to show an increasing trend. In particular, about 30% of these papers have emerged from authors in the university sector. This year marks the completion of 10 years of successful operations of AstroSat. We hope to celebrate the same with a scientific meeting. The "MeerKAT Absorption Line" survey team has released various large datasets resulting from their survey for public use. I sincerely hope various data products hosted by IUCAA, coming from different missions and surveys, are used by the large astronomy community.

IUCAA continue to spread A&A to different sections of the community. Astronomy Centre for Educators (ACE) of IUCAA includes Teaching Learning Centre (TLC), National Resource Centre (NRC) and International Astronomical Union's Office of Astronomy for Education (IAU-OAE). Their activities focused on spreading Astronomy activities to students and teachers from colleges and schools. National Science Day 2025 at IUCAA this year is marked with an inspiring series of school-level and public events for rural and urban audiences held throughout February. The culmination was an engaging and educational Open Campus Day on February 28. The celebrations attracted more than 7000 science enthusiasts of all ages from various parts of Maharashtra and showcased the theme of 'Science & Innovation at IUCAA', inspiring the youth. All staff and academics welcomed the public to explore IUCAA's scientific landscape. A variety of interactive exhibits, live demonstrations, and lectures were held across multiple campus locations, each offering a glimpse into the fascinating world of astronomy and astrophysics. To end the day, a public sky watch ensured that attendees enjoyed guided observations of celestial objects through advanced telescopes, deepening their connection with the cosmos.

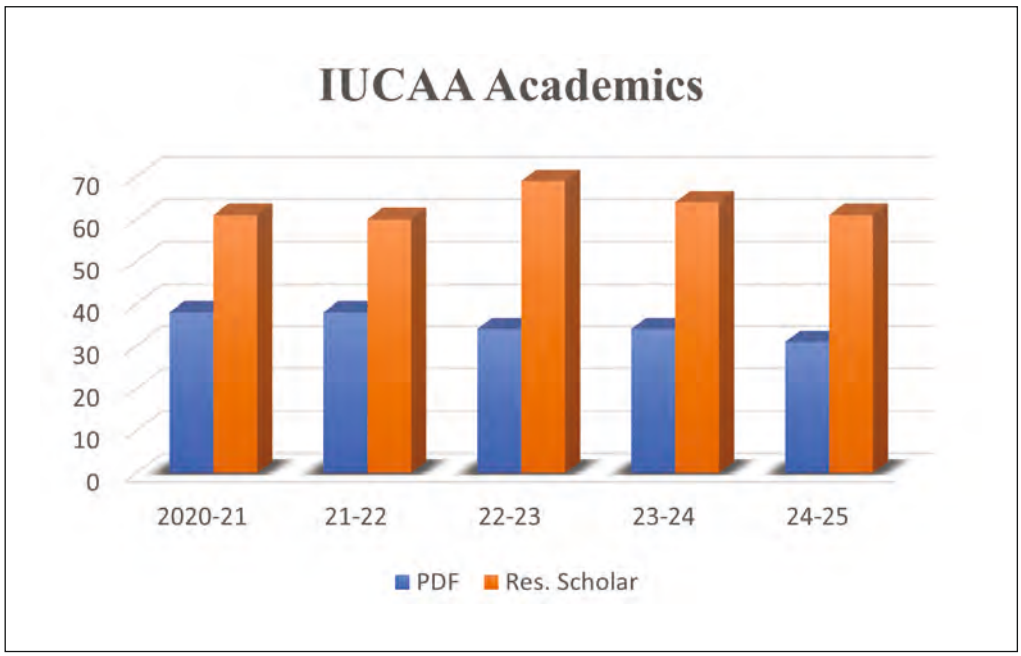
Finally, I take this opportunity to thank my colleagues and seniors at IUCAA for their help in performing my duties as the Director of IUCAA. I would like to express thanks to the Members of our Governing board and Council for their support and guidance. In particular, my thanks to Dr K. Kasturirangan (Chair, Governing Board till June 2024); Dr. K. N. Sathyanarayana (Chair, Governing Board) and Dr M. Jagadesh Kumar, Chairman, Governing Council. I also acknowledge the help, advice and support from the UGC and its officers and staff, and from the Ministry of Education of the Government of India.

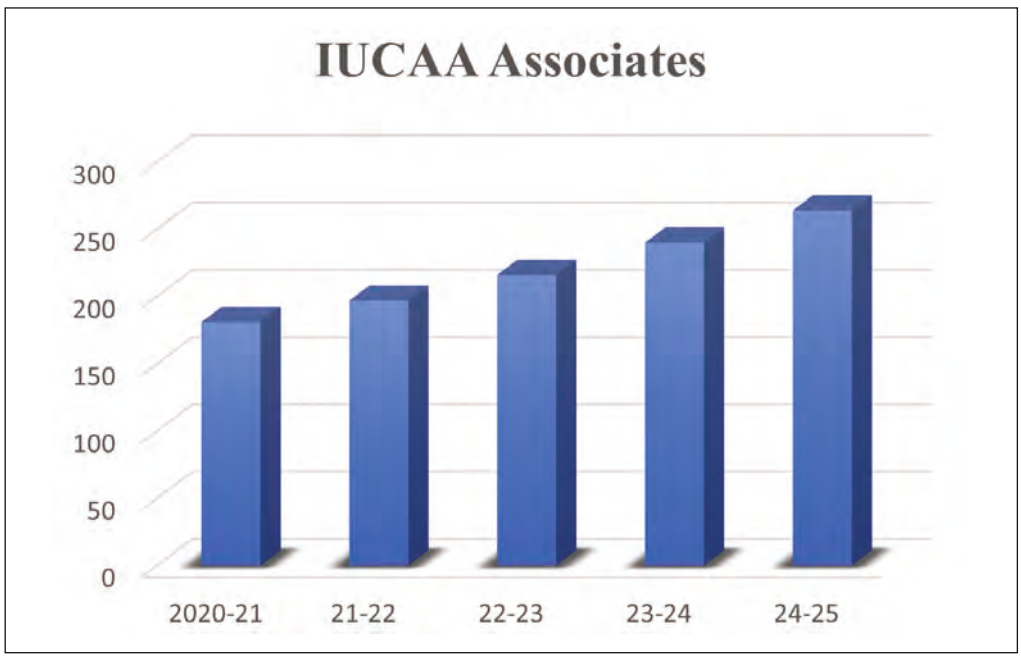
R. SRIANAND
Director, IUCAA

IUCAA IN NUMBERS

The IUCAA Family across the years

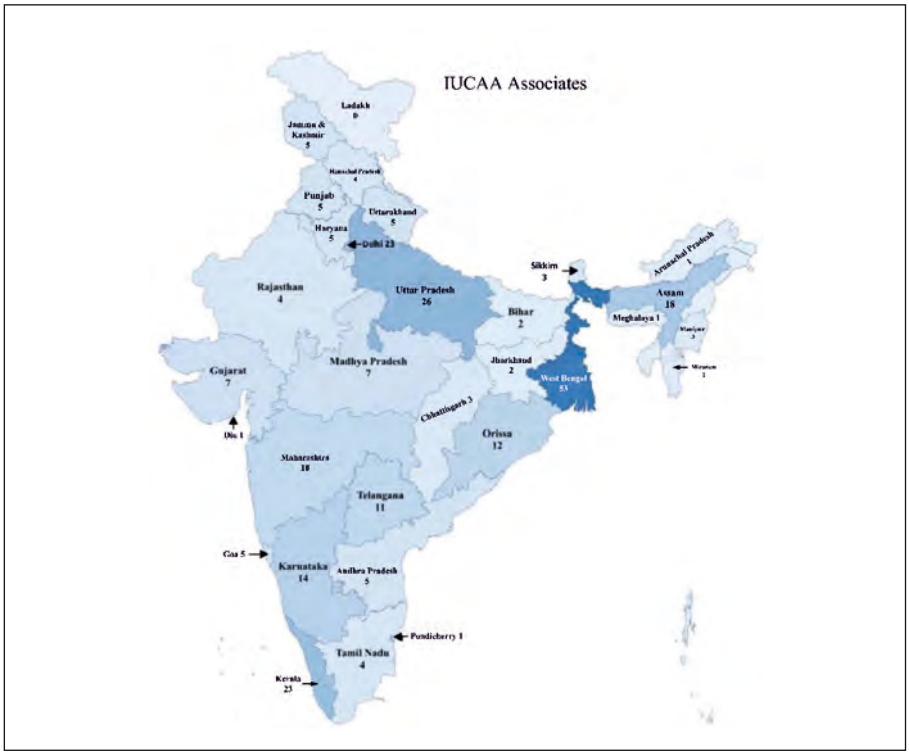
Since its inception, the IUCAA Research Scholars, Post-Doctoral Fellows and the Visiting Associates have seen a steady growth over time, with the academic strength today nearly thrice its original number





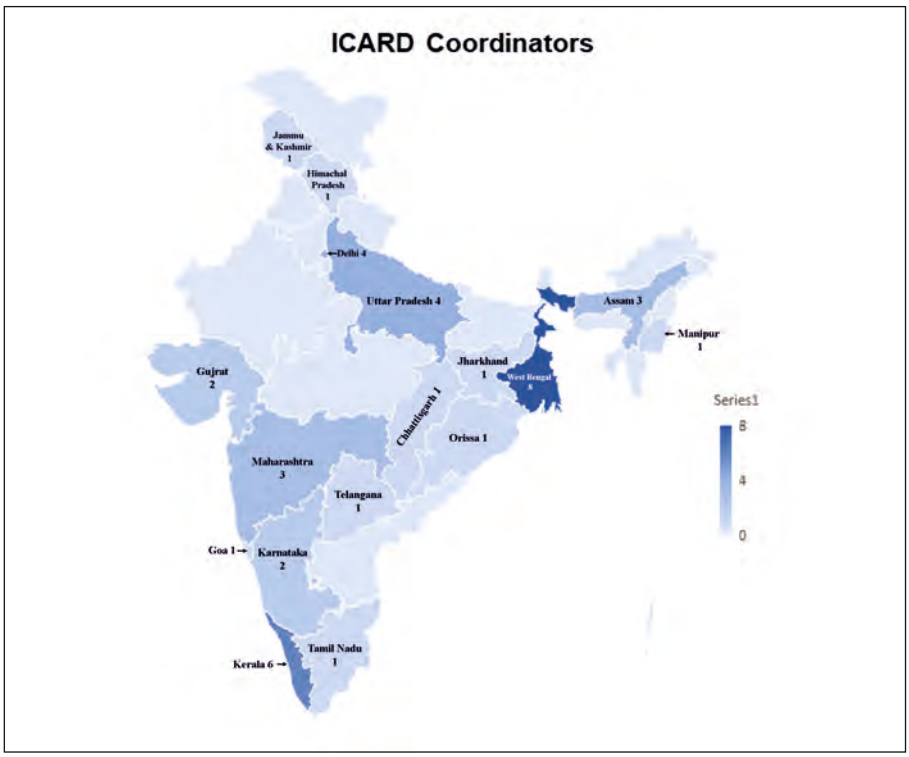
IUCAA Visiting Associates across India

The number of IUCAA Visiting Associates has continued to expand in numbers and geographically, with significant representation today from the remotest part of the country. The state-wise distribution of IUCAA Associates is depicted in the map. The number of Visiting Associates across India during 2024-25 was 264.



IUCAA Centre for Astronomy Research and Development (ICARD) across India

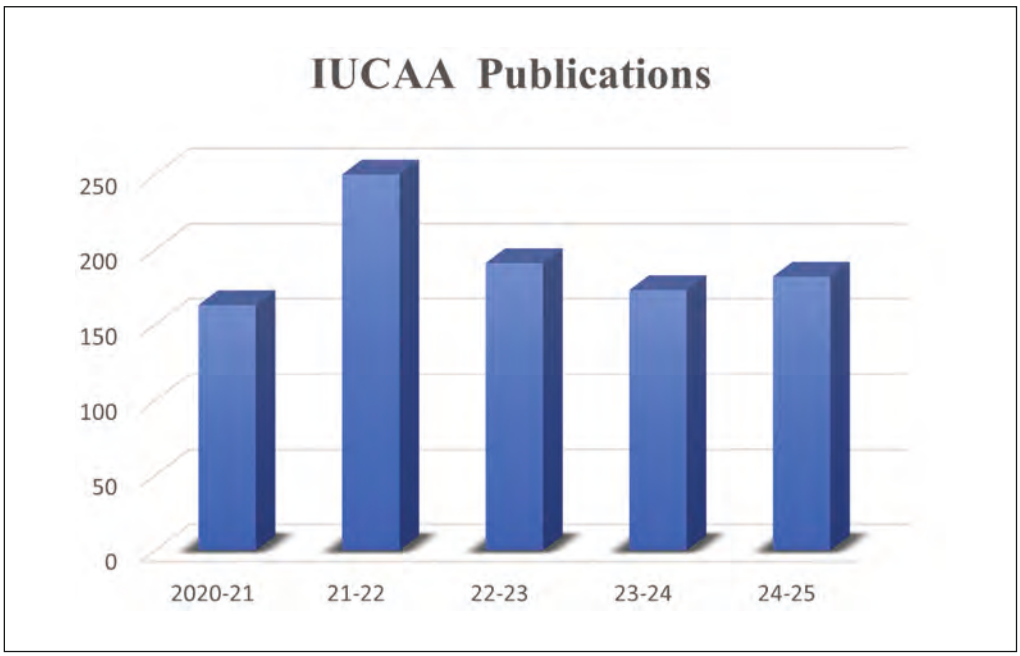
The number of ICARDs has continued to expand in numbers and geographically, with significant representation today from the remotest part of the country. The state-wise distribution of ICARDs is depicted in the map. The number of ICARDs across India during 2024-25 was 41.



Publications across the years

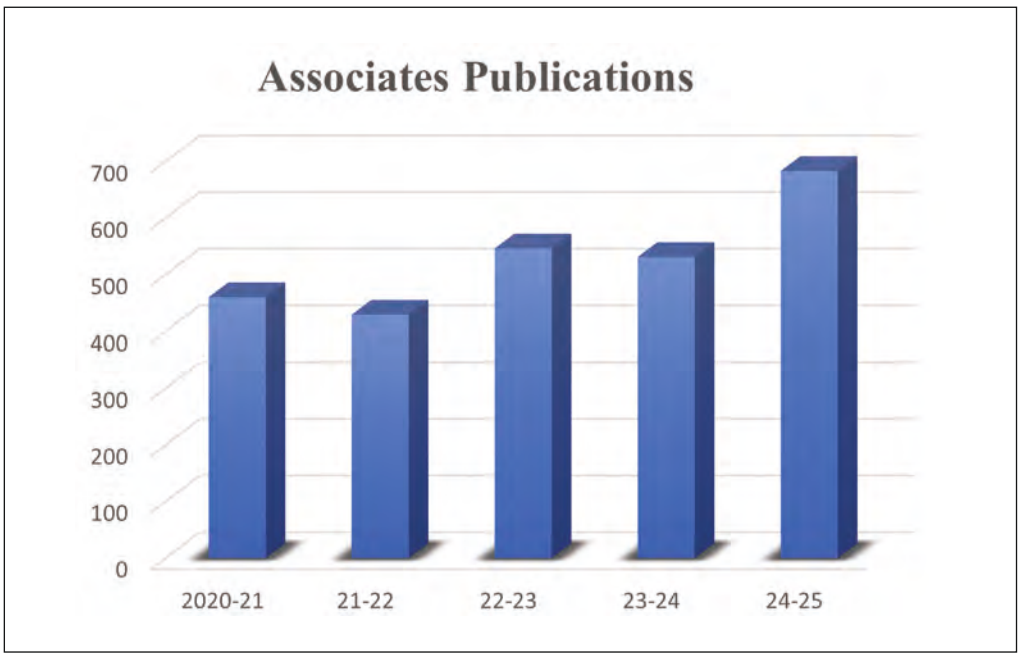
The plots depict the publications by IUCAA academics and Associates in the last five years. In 2024-25, there were 173 publications by IUCAA academics and 531 publications by IUCAA Associates.

The increasing academic strength has gone hand-in-hand with a corresponding increase in scientific output.

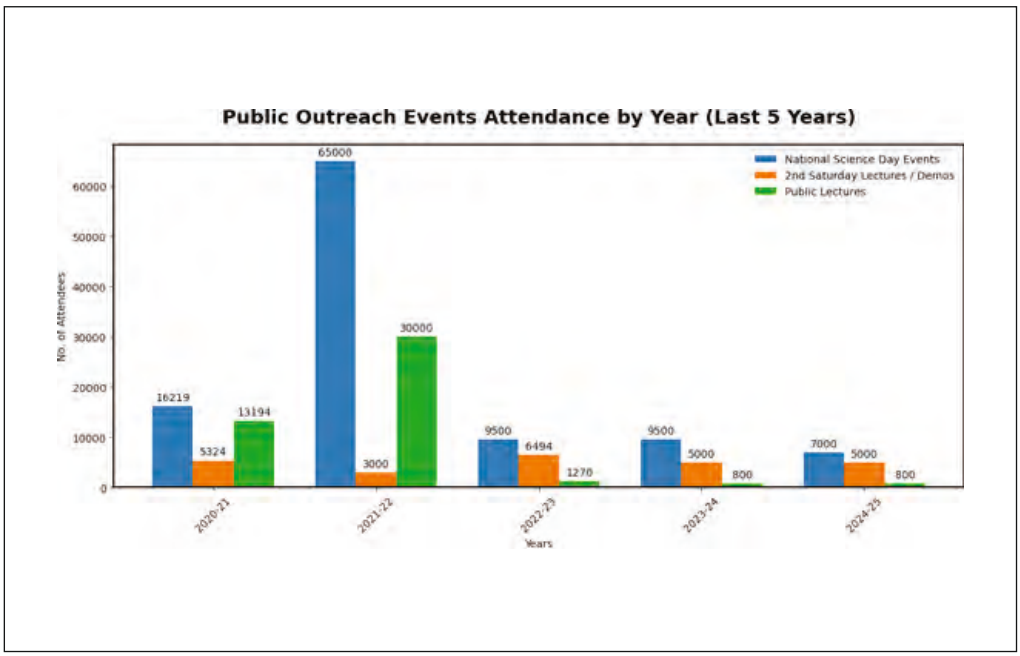


Publications across the year

The number of Publications by IUCAA visiting Associates are underestimated

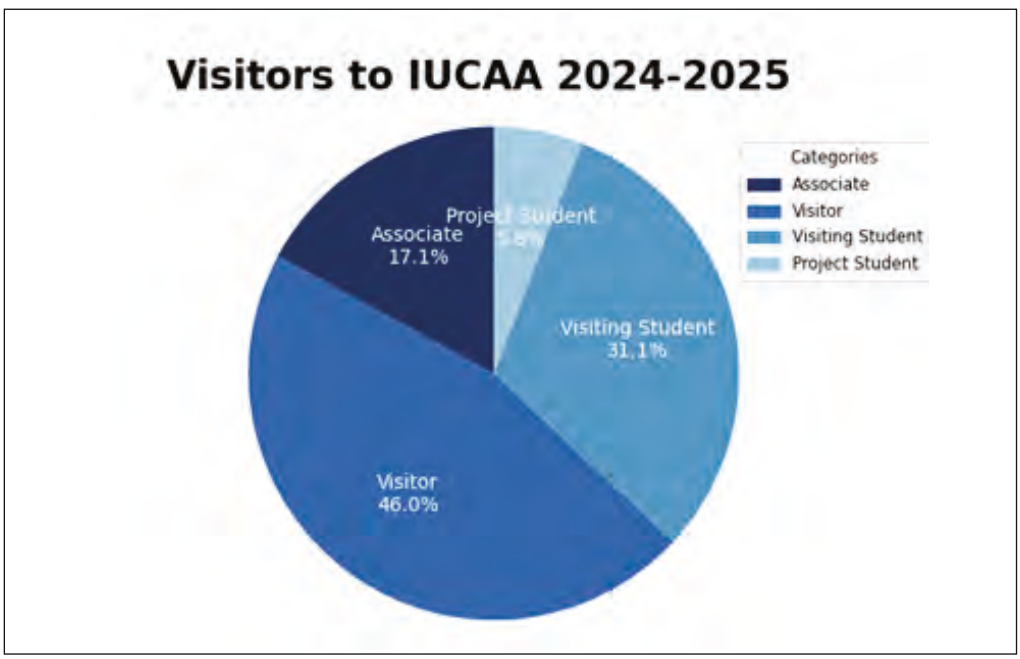


Public Outreach Events at IUCAA



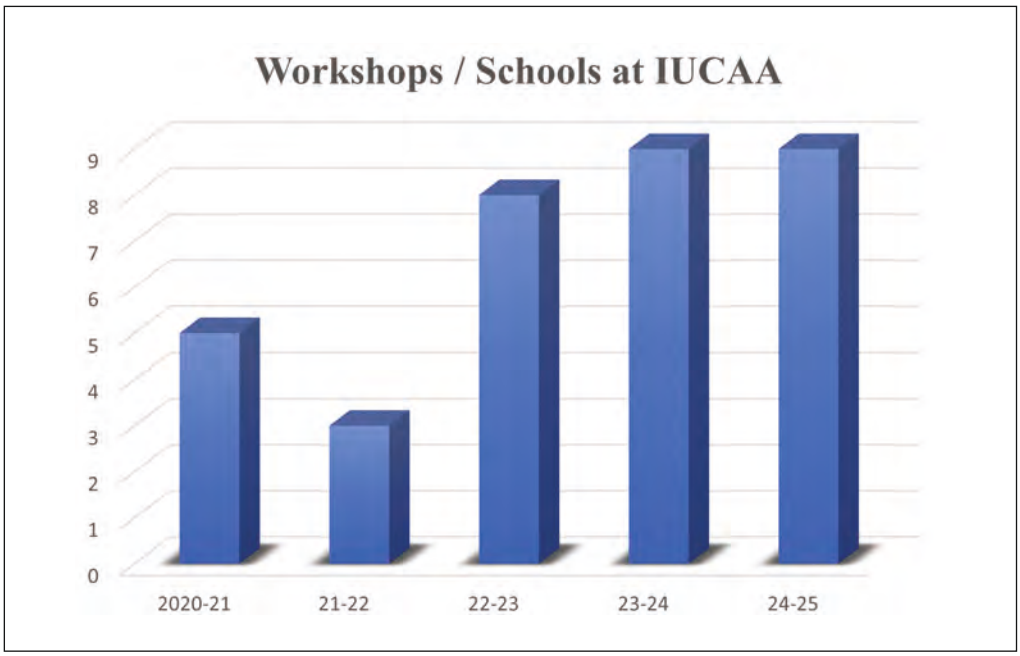
Visitors to IUCAA

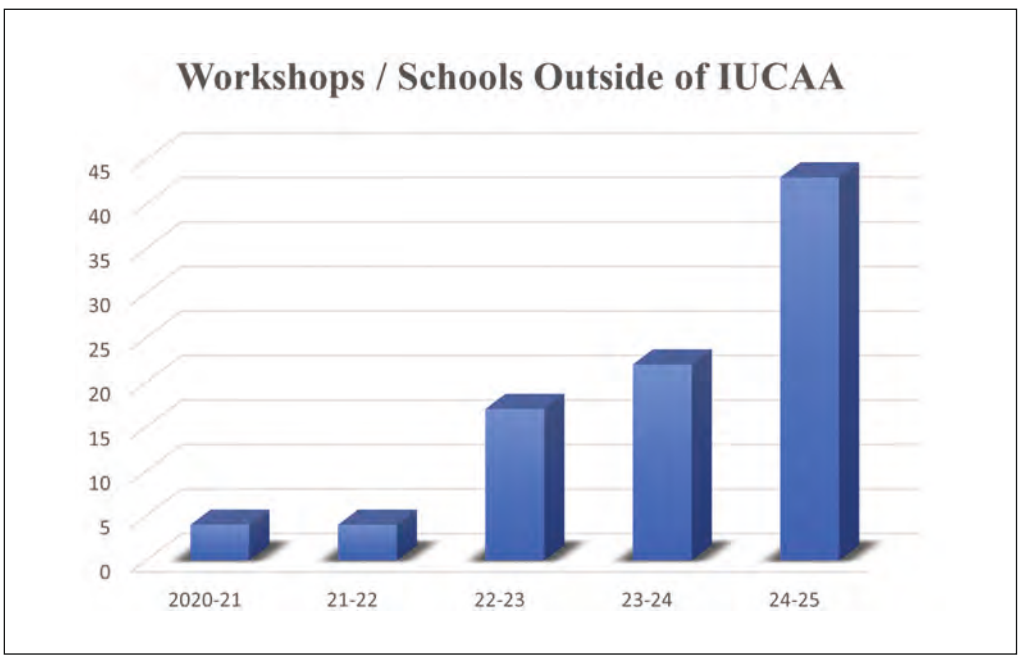
In addition to hosting Visiting Associates (17.1%), IUCAA hosted official visitors comprising of university academics (46%), students (31.1%) pursuing their Ph.Ds. from other universities / institutes, and project students (5.8%) working on projects supervised by IUCAA faculties. The total number of visitors in the period 2023-24 comprising the above-mentioned categories was 942.



Workshops/Schools in IUCAA and Outside IUCAA

IUCAA is committed to fostering astronomy and astrophysics in universities, primarily through an increasing frequency of workshops and schools, both at and outside IUCAA. The graph shows the distribution of workshops/schools held at IUCAA and outside IUCAA during the past five years, including 2024-25.





Introduction

In the recent past there have been significant developments in the domain of extragalactic astronomy, driven by ready access to large scale observational facilities and computational facilities. One of the fundamental questions in astronomy is understanding the history of evolution and assembly of galaxies since cosmic dawn. Several diverse astrophysical processes couple together at varying spatial and temporal scales to contribute to the above process. Stars in galaxies form from collapse of inhomogeneities in dense gas within the galaxy. Such gas supply to the galaxy is in turn regulated by the nature of interaction of local scale processes generated within the galaxy that affect the large scale gas reservoirs in the galaxy outskirts. Ionising radiation from the stars in the galaxy as well as the central Active Galactic Nuclei (AGN) contribute to such regulatory effects. Galaxy evolution are further influenced by mergers of galaxies co-evolving in local groups and clusters which provides another pathway of fresh induction of gas and stellar mass assembly. Several research groups at IUCAA have been studying different aspects of this topic through various focused efforts. The broad research goals and recent results pertaining to extragalactic astronomy from IUCAA researchers are highlighted below.

Galaxy evolution

Various physical processes such as gas inflows and outflows, galaxy mergers, stellar feedback etc. regulate growth of galaxies. The UVIT instrument onboard the ASTROSAT satellite have strongly contributed to this domain over the last few years. Some of the key highlights are summarised below.

- **The AstroSat UV Deep Field** The AstroSat UV Deep Field (AUDF) is an imaging survey carried out with the wide-field UltraViolet Imaging Telescope (UVIT) on AstroSat in two broad bands - F154W (1300 - 1800 Å) and N242W (2000 - 3000Å). AUDF South (PI: Kanak Saha) covers $\sim$ 236 arcmin^2 of the sky area, including the Great Observatories Origins Deep Survey (GOODS) South field. These observations reached a 3σ depth of 27.2 and 27.7 AB mag with a 50% completeness limit of 27 and 27.6 AB mag in the F154W and N242W filters, respectively in about 63000 sec of exposure time. A similar imaging survey called the AstroSat UV Deep Field North were carried out centred on the GOODS North field in three filters, namely, F154W (34000 sec), N245M (15500 sec) and N242W (19200 sec) of UVIT. AUDF North (PI: Kanak Saha) reached a 3σ depth of about 27 AB mag (see Mondal+2023, ApJS).

  With the acquired depth, AUDF South and North are the deepest far and near-UV imaging data covering the largest area known to-date at 1.2 – 1.6" spatial resolution. The galaxy counts distribution defined with a power-law slope of $\sim$ 0.43 dex mag^{-1} in the N242W filter matches well with Hubble Space Telescope/Wide-Field Camera 3/UVIS observations (see Saha+2024, ApJS). The primary science outcomes of these two deep field studies are outlined in subsequent sections.

- **Ionizing galaxies from Cosmic Noon** Within the first billion years after the Big Bang, our Universe went through a major phase transition known as reionization, a process in which neutral hydrogen atoms dissociated into protons and electrons when they were struck by high energy UV radiation with wavelengths less than 912 Å or energy greater than 13,6 eV. Understanding the cosmic reionization and the sources responsible for this process remains one of the frontier problems in astronomy.

  The Lyman continuum (LyC) emission can be easily absorbed or scattered by the gas and dust in the interstellar medium or the circumgalactic medium of their host galaxies. Even when some of these ionizing photons manage to escape

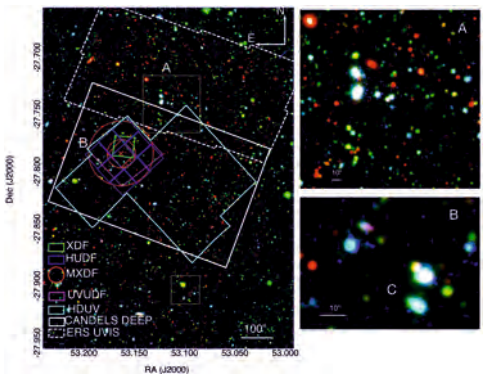


Figure 1: False color RGB image of the AstroSat UV Deep Field South (red: HST/ACS/F606W, green: N242W and blue: F154W). All images are PSF-matched and have same pixel scale as in F154W filter. The zoom-in ortion A and B are shown to highlight image quality and astrometric accuracy.

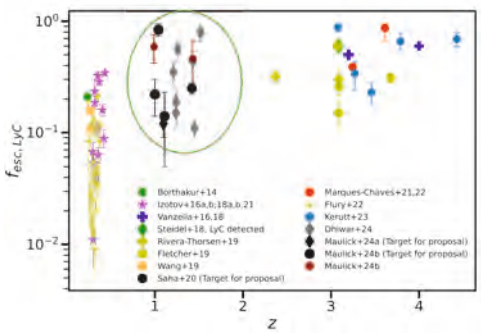


Figure 2: Absolute escape fraction of ionizing photons from estimated based on F154W detection in the redshift range $z \sim 1-2$. Data points marked within the ellipse are from UVIT detection and they probe rest-frame $\lambda_{rest} = 550-700\mathring{A}$.

from the host galaxy, they maybe absorbed by the vast intergalactic medium between us and the galaxy. This is why their detection used to be rare about a decade ago but becoming emergent in extragalactic astronomy nowadays. Over the last four years, Prof. Kanak Saha and group have detected 16+1 LyC leakers (one of them is an AGN) based on the F154W filter from AUDF South and North in the redshift range z 1 - 2. The absolute escape fraction of ionizing photons from the star-forming galaxies vary $\sim 10-60\%$ — making them the first coherent sample of ionising sources at Cosmic Noon, and thus bridging a gap between the Low-redshift Lyman Continuum survey at z 0.2 - 0.4 (LzLCS, Flury+2022, ApJS) and those at z 3 (Steidel+2018, ApJ, and references in Figure 3). Unlike most leakers detected to-date, the ionizing photons detected in the F154W filter of UVIT have their rest-frame wavelength in the range of $\lambda_{rest} \sim 550-700\mathring{A}$ - something unique about AstroSat. Most of these leaking galaxies have intense star formation rates, with some of them forming massive young stars at a rate 100 times higher than our Milky Way Galaxy. These results are published in a series of papers — Dhiwar+2024, ApJ Letters; Maulick+2024a, ApJ, Maulick+2024b, ApJ, Saha+2020, Nature Astronomy.

- **Probing galaxy growth using AUDF and cosmological simulations:**

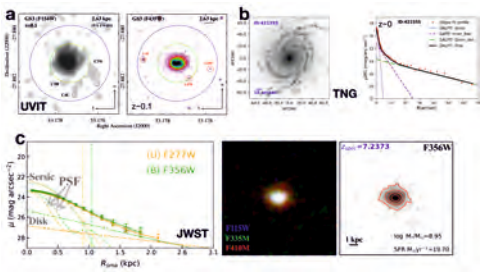


Figure 3: Panel **a**: A blue compact dwarf galaxy (GS3) at z=0.1 ($M_* \simeq 10^9 M_\odot$) observed by F154W/UVIT. The FUV clumps beyond the optical disk are detected with an SNR of ~ 4 has 25.2 - 25.3 AB mag. HST/WFC/F435W image of the galaxy on the right is PSF matched with UVIT. Panel **b**: A local massive galaxy with $M_* > 10^{11}$ $M_\odot$ from TNG50 simulation showing clear signature of an extended LSB disk besides an inner high surface brightness disk and Seric bulge. Panel **c**: A low-mass galaxy with $\log M_* = 8.95$ at z=7.2 observed by the JWST/NIRCam filters brimming with star formation at rate of 19.7 $M_\odot yr^{-1}$ derived based on SED fitting. Left panel showing intrinsic profile decomposition to show evidence of a disk component and middle panel showing the false color image of the galaxy.

Prof. Kanak Saha and his research group have utilized the AUDF data to probe how low-mass galaxies at z 0.1 - 0.3 grow their stellar mass via cold gas accretion. FUV clumps have been detected beyond the optical boundaries of blue compact dwarf galaxies and within the outer FUV radius. These clumps have no stellar continuum. Based on the Starburst99 model, the stellar population age of the clumps are found to be $\sim 7-12$Myr. Such young clumps are likely to have formed from cold gas accreted in the galaxy outskirts and they migrate to the central region within a billion year timescale or less. This study (Borgohain, Saha+2022, Nature) showed that 10 out of 14 BCDs have such extended FUV emission and in several cases they are clumpy. It is noted that the torques due to dynamical friction are not enough to bring the whole outer disks, which should fade into extended old disks and halos of today's BCDs. In a follow up work, Pushpak Pandey, Saha+2025 (in prep) found a massive disk galaxy with stellar mass $\sim 10^11 M_\odot$ at z=0.67 found an extended FUV disk with clumps — indicating cold gas accretion leading to young clump formation and clump migration is a viable route to galaxy growth. 1

Exploring the IllustricTNG50 galaxy population, especially ones with $M_* \geq 10^{11}$M$_\odot$, it is found that a small fraction ($\sim$ 12%) of such massive disks have extended low-surface brightness (LSB) disks in addition to a Sersic bulge and an high surface brightness disk (see Sarkar & Saha, ApJ, 2024). The presence of such extended LSB disks requires further investigation, especially follow the merger tree.

Going beyond the local universe and Cosmic Noon, Prof. Kanak Saha and group have investigated galaxy structures at redshift $z > 6$ (when our universe was less than a billion year old). Based on the JWST/NIRCam filter observations, it is found that the fraction of galaxies with disks drops to about 30% at $z \sim 6-9$. Finding concrete example of disk galaxies is a non-trivial task (due to PSF pedestal). In FigureX (c), we show an example of a galaxy at z=7.2 (spectroscopic confirmation) with evidence of a disk structure around the central spheroid. Note that the F277W filter probes restframe UV light (Borgohain, Saha+2025 in prep).

Baryons Beyond the Luminous Boundaries of Galaxies and Clusters

Galaxies are the building blocks of the universe. However, at any cosmic epoch, more than 90% of the ordinary matter in the universe resides outside galaxies in a diffuse gaseous form. The majority of these baryons are found in the intergalactic medium (IGM), with smaller fractions distributed in the circumgalactic medium (CGM) and the intracluster medium (ICM). Galaxies grow in mass and size by accreting those baryons from their surroundings. Conversely, large-scale galactic winds eject gas— along with heavy elements such as carbon, oxygen, and nitrogen produced within galaxies— back into these media. The physics of the evolution of such gas around galaxies and their impact on galaxy's growth is being studied through dedicated observational campaigns, as outlined below.

- **MUSEQuBES Survey at low-z** Prof. Sowgat Muzahid and his team are dedicated to understanding the exchange of baryons between galaxies, galaxy clusters, and their surrounding environments. He is leading major observational campaigns—in collaboration with an international team of scientists—to map the distribution of tenuous gas around galaxies and clusters and to characterize its physical properties. The team is conducting two large surveys, collectively known as the MUSE Quasar-Field Blind Emitters Survey (MUSEQuBES), targeting redshifts $z > 3$ and $z < 1$. These efforts are supported by high-quality observational data from world-class facilities, including the Hubble Space Telescope (HST), the Very Large Telescope (VLT), and the Keck Observatory.

  The low-z MUSEQuBES survey obtained 65h of MUSE observations of 16 fields centred on 16 intermediate-redshift ($z_{\rm qso} = 0.5 - 1.5$) quasars. A sample of $\approx$ 500 galaxies was designed for which CGM can be studied using HST/COS spectra of background quasars spectra. These low-z ($z \approx 0.3$), low-mass ($M_* \approx 10^{8.5}$ M$_\odot$) galaxies form stars only at a mild rate of $\approx$ 0.04 M$_\odot$ yr^{-1}. Several papers have been published/under preparation based on this survey (Dutta et al., MNRAS, 528, 3745, 2024; Dutta et al., ApJ, 980, 264, 2025; Dutta et al.

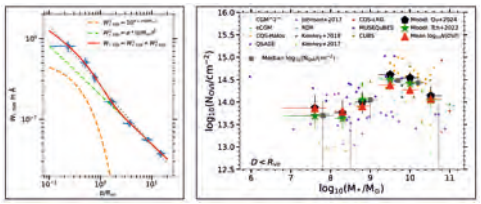


Figure 4: `Left:` The Lyα rest-frame equivalent width profile exhibits a change in slope near $R_{\rm vir}$, transitioning from a log-linear form within the virial radius to a power-law behaviour beyond it. `Right:` The average OVI column density measured within the virial radius of star-forming galaxies peaks at stellar mass $\approx 10^{9.5}$ M$_\odot$ and declines at both higher- and lower- stellar masses.

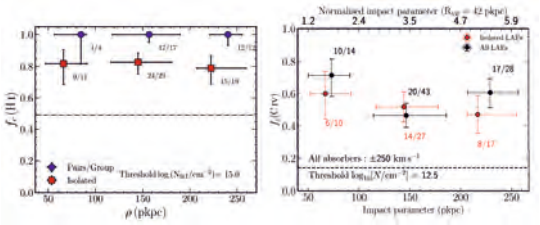


Figure 5: `Left:` The HI covering fraction, for a threshold column density of 10^{15} cm^{-2}, is shown as a function of galactocentric impact parameter for the isolated and non-isolated LAEs at $z \approx 3.3$. A significant fraction of these LAEs show strong HI absorption in their CGM out to $\approx$ 250 kpc. `Right:` Similar to the left panel but for CIV and for a threshold column density of $10^{12.5}$ cm^{-2}. In both panels, no significant trend of covering fraction with impact parameter is observed. However, group galaxies tend to exhibit somewhat higher covering fractions compared to their isolated counterparts.

2025,arXiv:2409.15423, ApJ accepted). The key results of these papers are summarized below:

(a) The Lyα rest-frame equivalent width (REW) profile changes its shape at around virial radius ($R_{\rm vir}$) from a log-linear in the inner regions to a power-law at larger distances, likely suggesting that the REW is dominated by the CGM at $\lesssim R_{\rm vir}$ and by galaxy-absorber clustering at large distances (see left panel of Fig. 4). (b) Outside the virial radius, the median stacked Lyα absorption profile can be explained purely by galaxy-absorber clustering. Therefore, it is argued that the extent of HI-rich CGM is $\approx R_{\rm vir}$. (c) The mean Lyα REW and HI covering fraction peaks for galaxies with stellar masses $M_* \sim 10^9$ M$_\odot$ and declines for both higher- and lower-mass galaxies. (d) The average OVI column density and covering fraction measured within the $R_{\rm vir}$ also show a similar behaviour, but with a peak at $M_* \sim 10^{9.5}$ M$_\odot$ (see right panel of Fig. 4). The virial temperatures of such galaxies are well suited for OVI production via collisional processes. (e) Even in dwarf galaxies, the CGM is enriched with OVI with a mean covering fraction of $\approx$ 50% and OVI mass of $\approx 10^{5.5}$ M$_\odot$. The majority of the OVI components associated with dwarf galaxies are bound to the host halos.

- **MUSEQuBES Survey at high-z** The high-z MUSEQuBES survey obtained 50h of MUSE observations of 8 fields centred on 8 high-z quasars ($z_{\rm qso} = 3.5 - 4.0$). Researchers built the first statistically significant sample of 96 Lyα emitters (LAEs; $z_{\rm lae} = 2.9 - 3.9$) from this data set in the foregrounds of the 8 quasars to study their CGM in absorption. It has been demonstrated that the stacked CGM absorption profiles can be used to correct Lyα redshifts statistically, which are otherwise affected by resonant scattering (Muzahid et al., MNRAS, 496, 1013, 2020). Researchers report significant excess HI and CIV absorption near the LAEs out to 500 kms^{-1} and at least $\approx$ 250 kpc. The absorption is significantly stronger around the $\approx$ 1/3 of the LAEs that are part of 'groups', which is attributed to the large-scale structures in which the LAEs are embedded (Muzahid et al., MNRAS, 508, 5612, 2021).

  Through detailed Voigt profile fitting analysis column (N) densities of CIV and HI absorbers has been measured for the 8 quasar's spectra. Exploiting those measurements the covering fraction of gas and metals in the CGM of high redshift galaxies has been estimated. The LAEs show an overall HI covering fraction of $\approx$ 88% for a threshold column density of 10^{15} cm^{-2} (Banerjee et al. ApJ, 980, 171, 2025). Notably, at the same threshold, the LAEs in pairs/groups exhibit a 100% HI covering fraction out to $\approx$ 250 kpc. In contrast, isolated LAEs consistently show a lower covering fraction of $\approx$ 80% (see left panel of Fig. 5).

  We further measured a covering fraction of 60%

for a threshold $N(CIV)$ of $10^{12.5}$ cm^{-2}, which is roughly twice as high as in random regions. The CIV covering fraction remains constant at $\approx$ 50% for impact parameters in the range of $150 - 250$ pkpc ($\approx 3 - 6R_{200}$; see right panel of Fig. 5). Using the covering fraction profile, the LAE–CIV absorber two-point correlation function was constrained. The CIV covering fraction is found to be enhanced for the LAEs that are part of a 'pair/group' compared to the isolated ones (Banerjee et al., MNRAS, 524, 5148, 2023).

Using a novel combination of dual emission and absorption line studies, **Banerjee et al., ApJL, 979, 32, 2025** reported the detection of an elusive cosmic web filament traced by seven LAEs. The filament is detected via Lyα emission, likely powered by in-situ recombination. This discovery is the first of its kind for which the metallicity of the filament could be successfully constrained using complementary absorption-line techniques, revealing its primordial nature. Notably, unlike previously known systems near quasar neighbourhoods, none of the seven galaxies associated with the filament exhibit any evidence of quasar-like properties.

1

- **Probing the Outskirts of Galaxy Clusters** Owing to the lack of sensitive emission line diagnostics to probe the cool/warm-hot gas that prevails in cluster outskirts (i.e., $\rho > R_{500}$), the outskirts of galaxy clusters remained poorly understood. By cross-matching SDSS cluster and quasar catalogs from the literature, (Mishra & Muzahid, ApJ, 933, 229, 2022) built the largest sample of $\approx 80,000$ background quasar-foreground cluster pairs probing impact parameters from $1 - 5 \times R_{500}$. They reported the first statistical detection of MgII in the outskirts of these clusters indicating the presence of metal-rich, cool gas. They suggested that the observed MgII arises from stripped materials and that gas stripping may be important out to large clustocentric distances ($> 3R_{500}$).

  Later, by cross-matching the Hubble Spectroscopic Legacy Archive quasar catalogue with optically- and SZ-selected cluster catalogues, we presented the first detection of cool, neutral gas in the outskirts of low-z galaxy clusters using a statistically significant sample of 3191 $z \approx 0.2$ background quasar–foreground cluster pairs (Mishra et al., MNRAS, 527, 3858, 2024). The covering fractions measured for Lyα (21%), CIV (10%), and OVI (10%) in cluster outskirts are significantly lower than in the CGM of galaxies at similar redshifts. We further reported that the CGM of galaxies located closer to cluster centers, or those residing in massive clusters, is significantly deficient in neutral gas– indicating the effects of CGM stripping in cluster environments.

- **Investigating the Circumgalactic Medium using different techniques** The diffuse halo of multiphase gas around galaxies or the circumgalactic medium (CGM), which acts as the interface between galaxies and the wider environment, is a key aspect of galaxy evolution. The most viable method of studying the diffuse CGM gas has been through absorption against a bright background source such as a quasar. Over the last few years, Rajeshwari Dutta and collaborators have contributed significantly in statistically characterizing the distribution and physical conditions of the multiphase CGM gas by cross-correlating absorption lines and large galaxy surveys (e.g., Dutta et al., 2020, MNRAS, 499, 5022; Dutta et al, 2021, MNRAS, 508, 4573, Galbiati et al., 2024, A&A, 690A, 7; Beckett et al., 2024, ApJ, 974, 256).

  However, absorption-line measurements along pencil-beam sight-lines are generally unable to provide a complete mapping of the CGM gas distribution. Systems in which it is possible to conduct spatially-resolved studies of the CGM in absorption using gravitational lenses or multiple background sources are rare. Rajeshwari Dutta and collaborators recently conducted a unique tomographic analysis of the structure of metal-enriched cool gas in the CGM of galaxies at redshifts, $z < 2$. Diffuse gas is detected in absorption in the spectra of two background quasars at $z \sim 2 - 3$, which are two of the few currently known quasars with multiple images due to strong gravitational lensing by foreground galaxy clusters. The results of this study (Dutta et al., 2024, MNRAS, 528, 1895) indicate that the metal-enriched gaseous structures around galaxies become less coherent with increasing distance, with a likely coherence length scale of ~ 10 kpc.

  On the other hand, detecting emission in multiple lines from the diffuse gas in the CGM can

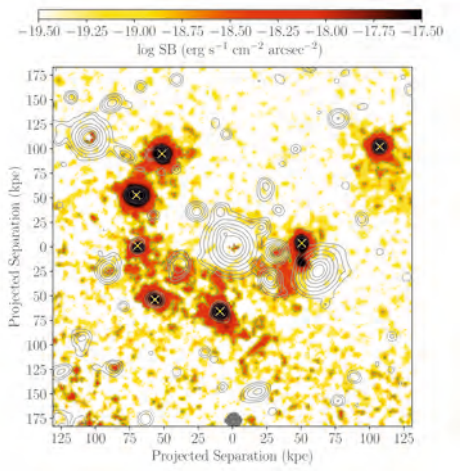


Figure 6: Rajeshwari Dutta and collaborators recently mapped the warm gas traced by doubly ionized oxygen emission lines around a group of seven galaxies (marked by yellow crosses) about 8 billion years ago. The extended emission (outlined by green contours) most likely arises due to interactions between the galaxies, and traces filamentary structures spanning about 650,000 light years.

provide us with additional and complementary insights into the distribution and physical conditions of the CGM. However, it used to be challenging to study the faint emission from the diffuse gas around galaxies located at large distances from us due to an effect called cosmological surface brightness dimming. The advent of sensitive, wide-field optical integral field unit spectrographs such as the Multi-Unit Spectroscopic Explorer (MUSE) on the Very Large Telescope (VLT) has revolutionized the study of CGM in emission. Recently, Rajeshwari Dutta and collaborators have detected, for the first time, the average extended emission from the metal-enriched gas around a general population of galaxies at $z < 2$ (Dutta et al, 2023, MNRAS, 522, 535 and Dutta et al., 2024, A&A, 691A, 236). By stacking the MUSE 3D data of a statistical sample ($\sim$ 600) of galaxies from two large surveys, these studies characterized the average emission in MgII, [OII], [OIII], and Hβ lines up to $\sim$ 40 kpc around galaxies, and investigated the connection of CGM gas in emission and galaxy properties.

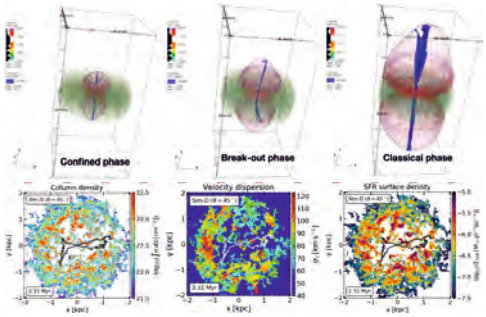


Figure 7: Top: 3D visualisation of a jet breaking out of a kiloparsec scale gas disk. The different evolutionary stages of the jet are depicted, with the early phase indicating strong coupling of the jet with the ISM, followed by a break-out phase and a classical phase of jet proceeding through homogeneous gas. Bottom:

Numerical simulations of extragalactic astrophysical phenomenon

Advanced numerical simulations have become an integral part of astrophysics thanks to improvements in availability of computational resources. Such simulations model evolution of stellar distribution and fluid flows in and around galaxies, helping constrain various astrophysical phenomenon. At IUCAA, research group led by Prof. Dipanjan Mukherjee has been working a diverse array of problems related to the topic of AGN feedback, with a specific on the impact of relativistic jets from supermassive blackholes (SMBH) on their environment. Large scale jets from SMBH are known to be strong driver of galaxy evolution. They heat up the gas in the galaxy's environment preventing run-away cooling as well as regulating in-situ gas dynamics in the form of outflows, turbulence and shocks. Prof. Mukherjee's group, along with international collaborators, have been attempting to understanding the various facets of this phenomenon, which can broadly be grouped in to the following sub-categories outlined below.

- **Simulations of jet-ISM interaction** Compact kpc scale relativistic jets from are expected to first proceed through the Interstellar medium (ISM) of the host galaxy, before evolving to larger scales. Researchers at IUCAA have been actively pursuing modelling such phenomenon through high resolution simulations with real-

istic distribution of the dense gas. A typical simulation (from Mukherjee et al. 2018) is presented in Fig. 7 which shows a relativistic jet breaking out of the confines of the kpc scale gas disk. Over the past 5 years, several new physics based modules have been added to the numerical architecture to improve the modelling of such systems. One such addition is the implementation of a turbulence regulated framework for estimating starformation rates in such simulations (Mandal et al. 2021). This necessitated the development of a fast Poisson solver to evaluate the self-gravity of the gas distribution, which has been subsequently integrated (Mandal et al. 2023) into the open source MHD code "PLUTO". As an ancillary investigation, a large suite of well resolved simulations of AGN winds interacting with clouds were carried out, to specifically test for the impact of self-gravity (Mandal et al. 2024) on cloud survivability and starformation. This served as a precursor to larger scale simulations with a novel implementation of a star-particle module (A. Mandal, PhD thesis). The above works have provided several novel new results: a) The galaxy goes through different evolutionary phases, depending on the coupling of the jet with the ISM. The initial phases are marked by decline in starformation, followed by an increase. b) Gas directly impacted by the jet beam can undergo positive feedback, but with reduced efficiency. c) Self-gravitational forces in large molecular clouds can prevent large scale destruction of clouds for less powerful winds. d) Inclusion of estimates of turbulent velocity dispersion and local Mach number is crucial for estimating starformation rates in clouds, which has been ignored so far. The above results have been obtained based on simulations carried by Prof. Mukherjee' research group, using HPC facilities at IUCAA and other international resources.

- **Observations of jet-ISM interactions and related predictions** To augment the predictions from simulations, a series of observational campaigns have been carried out by international teams of researchers, in collaboration with Prof. Mukherjee and his research group members at IUCAA. The observations were carried out using an array of international observational facilities such as ALMA, VLT, JWST etc. To aid interpreting the observational results, IU-

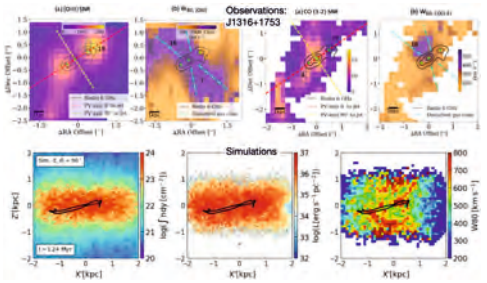


Figure 8: Top: Representation of the top two panels of Fig. 5 and 6 from Girdhar et al. 2022 (DM as co-author) showing enhanced kinematics in ionised and molecular gas of J1316+1753, a prototype of multi-phase observation of jet-ISM interaction. Bottom: Representation of the middle panel of Fig. 8 of Meenakshi et al. 2022, showing predicted [OIII] emission and line widths (W80) from simulations of jet-ISM interaction, with enhanced widths perpendicular to the jet, as also observed in multi-phase observations, such as top panel.

CAA researchers have presented detailed predictions from the simulations of the jet-ISM interactions outlined above (Meenakshi et al. 2022a,b). An exmaple of such an effort is presented in the lower panel in Fig. 8. The results of these studies provides quantitative estimates of the changes in the gas motions as a result of shocks injected by the jet. The distribution and measure of such disturbed kinematics has helped model the jet-ISM interaction in several galaxies. Direct comparison with numerical simulations have been performed for several sources such as IC 5063 (Mukherjee et al. 2018), 4C 31.04 (Mukherjee et al. 2019), B2 0258+35 (Murthy et al. 2022, 2025, Fabbiano et al. 22), 2MASSX J23453269-044925 (Nesvadba et al. 2021), (Mulard et al. 2023) and the Tea Cup galaxy (Audibert et al. 2023); besides other studies where jet-ISM interactions have been investigated motivated by the simulations such as UGC 05771 (Zovaro et al. 2020), 4C 41.17 (Nesvadba et al. 2020), J1316+1753 (Girdhar et al. 2022, 24), 3C 326 (Leftley et al. 2024) etc. Prof. Mukherjee and his research group members have been active contributors to the above publications. Such a wide array of observational results strongly support the theoretical predictions from the simulations. New simulations with added physics based models and updated numerical tools are being

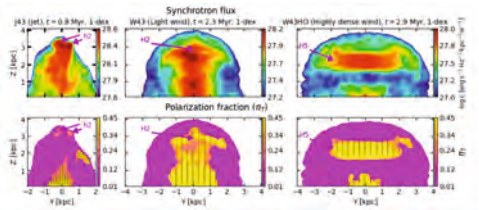


Figure 9: A comparison of synchrotron emission (top) and polarisation (bottom) maps for a typical kpc scale relativistic jet (left) and two models of non-relativistic winds (middle and right). The maps have been convolved with a Gaussian function to represent realistic observable resolutions. The images show clear distinction of morphology of emission between the jets and winds, which can be used as a guide to ascertain the cause of the observed radio emission in large scale surveys.

implemented.

- **Non-thermal emission of jets and MHD instabilities** Another area of focus of in the current context is the exploration of large scale dynamics of jets as a function of different fluid parameters in general and the impact of MHD instabilities. A key component of interest is the evolution of particle acceleration at shocks at the head of the jet as well as turbulent structures creating shocks inside the jet's cocoon. Prof. Mukherjee's group, in collaboration with researchers from University of Torino, Observatory of Torino and IIT Indore, have developed a novel hybrid scheme to evolve cosmic ray electrons along with a background relativistic fluid flow, duly accounting for energy losses due to radiation and diffusive shock acceleration modelled as a sub-grid phenomenon. Such modules have been used to investigate how different types of MHD instabilities such as kink and Kelvin-Helmholtz modes affect the shock acceleration, and in turn synchrotron radiation (Mukherjee et al. 2020, 2021). Such models have been further applied to carry out a suit of simulations to study the evolution of kpc scale relativistic jets and non-relativistic winds in an ambient environment with turbulent magnetic field (Meenakshi et al. 2023, 2024). Detailed analysis of the synchrotron emission and polarisation (see Fig. 9) characteristics were carried to provide distinctive clues to help disentangle the source of such observed radio emission in observational surveys. Such works will be crucial in forthcoming large scale observational programs to help identify the nature of the source powering outflows observed in radio bands.

IUCAA IN NEWS

for the period April 01, 2024, to March 31, 2025

1. विश्व निर्मितीच्या रहस्यावरील संशोधनाची समकालीन 'साठ' वणूक
   Loksatta, Pune June 11, 2024, Page no. 1 & 15
2. **JWST spots earliest-known galaxy: What a new study**
   Indian Express, Pune, June 03, 2024, Page no. 12
3. स्फोटक ताऱ्यांची निर्मिती करणाऱ्या आकाशगंगेचा शोध
   Pudhari, Pune June 12, 2024, Page no. 7
4. **Astronomer's find ring galaxy 30 million light years from Milky Way**
   Hindustan Times, Pune, June 12, 2024, Page no. 4
5. आकाशगंगेजवळ तारनिर्मितीचा स्फोटक कारखाना
   Sakal, Pune June 15, 2024, Page no. 4
6. एल -१ भोवती पहिली परिक्रमा पूर्ण
   Maharashtra Times, Pune, July 03, 2024, Page no. 10
7. विज्ञान साहित्याची नवी झेप!
   Maharashtra Times, Pune, July 19, 2024, Page no. 6
8. मराठी विज्ञान कथेचा परीघ
   Sakal, Pune July 19, 2024, Page no. 6
9. एक अलौकिक शास्त्रज्ञ
   Samana, Pune July 24, 2024, Page no. 4
10. अंतराळ संशोधनात कृत्रिम बुद्धिमत्तेचा वापर
    Sakal, Kolhapur August 01, 2024, Page no.17
11. सूर्य पाहिलेला 'आदित्य एल वन '
    Sakal, Kolhapur, August 01, 2024, Page no.1
12. अवकाश उलघडण्यासाठी महाप्रकल्प ... महाप्रयोग
    Sakal, Kolhapur, August 02, 2024 Page no.17
13. **When perseverance paid off after Isaac Newton's tree refused to take root in Pune**
    The Sunday Express, Pune, August 25, 2024, Page no. 4
14. **IUCAA part of int'l team that measured 'cosmic dipole effect'**
    Indian Express, Pune, September 04, 2024, Page no.10
15. अवकाशाची एक बाजू लालसर, तर दुसरी निळसर
    Pudhari, Pune September 04, 2024, Page no. 2
16. **IUCAA part of int'l team that measured 'cosmic dipole effect'**
    Indian Express, Pune, September 04, 2024, Page no.10
17. **Int'l collaboration helps measure the cosmic dipole effect**
    Hindustan Times, Pune, September 05, 2024, Page no. 3
18. तब्बल नऊ लाखांहून ज्यास्त रेडिओ स्रोतांचा शोध
    Sakal, Pune, September 07, 2024, Page no. 4
19. **50 Pune scientists ranked among top 2% in the world**
    Indian Express, Pune September 20, 2024, Page no. 4
20. 'स्टॅनफोर्ड' च्या यादीत दबदबा
    Maharashtra Times, September 22, 2024, Page no.3
21. विश्वरूप दर्शनासाठी "आयुका " ची भरारी
    Saptahik Sakal, Pune, October 12, 2024, Page no.42
22. कृष्ण विवराभोवती तारकीय मलब्यातून नाट्यमय उद्रेक
    Prabhat, Pune, October 11, 2024, Page no. 3
23. दर ४८ तासांनी कृष्ण विवरांभोवती ताऱ्यांचे स्फोट
    Pudhari, October 10, 2024, Page no. 8
24. **NASA, Astro Sat capture dramatic eruptions from stellar wreckage around massive black hole.**
    Hindustan Times, Pune, October 12, 2024, Page no. 8
25. **Pune Scientists shed light on how Universe woke from 'dark ages'**
    Times of India, Pune, October 16, 2024, Page no. 8

26. कृष्णविवरांतही भरती-ओहटी अन बाष्पीभवनांची प्रक्रिया
Pudhari, Pune, November 06, 2024, Page no. 7

27. **New research shows Vaidya radiation may enable Hawking radiation in black holes.**
Indian Express, Pune, November 06, 2024, Page no. 7

28. इसरो २०३१ पर्यंत बांधणार 'स्पेस स्टेशन'
Pudhari, Pune, November 22, 2024, Page no. 3

29. भारताचीही आता 'स्पेस टेलिस्कोप' ची योजना
Maharashtra Times, Pune, November 22, 2025, Page no.1

30. **ISRO plans to set up lunar base with human presence by 2047**
Times of India, Pune, November 22, 2024, Page no. 6

31. **Indian astronomers discover cosmic web filament from 11.7 billion years ago using Very Large Telescope**
Indian Express, Pune, January 30, 2025, Page no. 4

32. वैश्विक जाळ्याच्या तंतूचा शोध
Loksatta, Pune, January 30, 2025, Page no. 20

33. **Cosmic web filament from 11.7bn years ago discovered**
Times of India, Pune, January 31, 2025, Page no. 4

34. **Indian astronomer-led scientist team discovers cosmic web filament from 11.7 billion years ago**
Hindustan Times, Pune, February 01, 2025, Page no. 5

35. **LIGO-India event held to educate Hingoli residents on proposed gravitational wave detector**
Indian Express, Pune, February 9, 2025, Page no. 5

36. **Lecture at Fergusson College delves into 'mysterious origin' of gold**
Indian Express, Pune, February 25, 2025, Page no. 4

37. **IUCAA TO HOST JAPANESE DELEGATION**
Hindustan Times, Pune, February 25, 2025, Page no. 6

38. **Talks to live demonstrations: Various institutions to celebrate National Science Day on February 28**
Indian Express, Pune, February 26, 2025, Pune, Page no. 5

39. **STEM talks, skywatch & interactive exhibits for science Day on Friday**
Times of India, Pune, February 26, 2025, Page no. 3

40. 'सूट' उपकरणाद्वारे सौर ज्वाळांचा वेध
Loksatta, Pune, February 28, 2025, Page no.16

41. राष्ट्रीय विज्ञान दिनी संशोधनाचा अनोखा योग
Maharashtra Times, Pune, February 28, 2025, Page no. 5

42. विद्यार्थ्यांनी अनुभवाला नारळीकरांनी भेटण्याचा योग
Sakal, Pune March 01, 2025, Page no. 2

43. उलगडली विज्ञानाची किमया
Maharashtra Times, Pune, March 01, 2025, Page no. 4

44. **National Science Day Celebrated**
Indian Express, Pune, March 01, 2025, Page no. 4

45. आत्मनिर्भर भारताचे क्वांटम मिशन
Saptahik Sakal, Pune, March 01, 2025, Page no. 10

46. अनोख्या सौरज्वाळा टिपल्या
Pudhari, Pune, March 3, 2024, Page no. 7

47. इसरो, नासा अभ्यास सहलीसाठी विध्यार्थ्यांची निवड आयुका करणार
Pudhari, Pune, March 25, 2025, Page no. 3

48. 'नासा', 'इसरो' ला जाणाऱ्या विद्यार्थ्यांची होणार परीक्षा
Sakal, Pune March 25, 2025, Page no. 3

49. **Pune ZP to send 75 students to NASA & ISRO**
Times of India, Pune, March 25, 2025, Page no. 3

IUCAA ACADEMIC CALENDAR

Annual Events at IUCAA 2024-25

Refresher Course on Astronomy and Astrophysics
Date: May 13- June 14, 2024

Summer School on Astronomy and Astrophysics (online)
Date: May 13- June 14, 2024

Meeting of the Scientific Advisory Committee
Date: April 22 – 26, 2024

Visit of the French Consul General and Consular team at IUCAA
Date: July 22, 2024

Foundation Day
Date: December 29, 2024

National Science Day
Date: February 28, 2025

Events at IUCAA

GW Open Data Workshop (ODW) by the LIGO-Virgo-KAGRA collaboration.
Date: April 18-20, 2024
Coordinators: Apratim Ganguly | Sanjit Mitra

Tutorial on IGWN-DHTC-OSG
Date: September 09 - 11, 2024
Coordinator: Sandeep Joshi | Sanjit Mitra

Gravitational-Wave Instrumentation Workshop
Date: November 10 - 29, 2024
Coordinators: Shasvath Kapadia

Baryons Beyond Galactic Boundaries - 2024
Date: December 02 - 06, 2024
Coordinators: Sowgat Muzahid | Raghunathan Srianand

LIGO India All-hands
Date: December 10 - 11, 2024
Coordinators: Subhadeep De (IUCAA)

17th Radio Astronomy Winter School
Date: December 14 - 24, 2024
Coordinators: Rajeshwari Dutta (IUCAA) and Subhashis Roy (NCRA)

AI/ML Applications to Astronomy & Astrophysics
Date: January 06 - 10, 2025
Coordinators: Ajit Kembhavi | Kanak Saha | Arif Babul

2nd Daksha Workshop: Indian Eyes on Transients Skies
Date: March 29 - 31, 2025
Coordinators: Gulab Dewangan (IUCAA) | Varun Bhalerao (IIT Mumbai)

Events outside IUCAA

Introductory Workshop on Astrophysics and Cosmology
Place: Department of Physics, Integral University, Lucknow, Uttar Pradesh
Date: May 02 - 04, 2024
Coordinators: M. Shahalam (Integral University, Lucknow) | Aseem Paranjape (IUCAA, Pune)

High-Performance Computing in Science
Place: ICARD, Department of Physics, University of Kashmir, Jammu and Kashmir
Date: May 22 - 24, 2024
Coordinators: Manzoor A. Malik (University of Kashmir) | Sanjit Mitra (IUCAA, Pune)

Summer School in Theoretical (Astro) Physics
Place: Department of Physics & Electronics, St. Xavier's College (Autonomous), Ahmedabad
Date: June 03 - 08, 2024
Coordinators: Gurudatt Gaur (St. Xavier's College, Ahmedabad) | Sanjit Mitra (IUCAA, Pune)

Workshop on Relativistic Cosmology: Theoretical and Data Analysis Techniques
Place: G. H. Raisoni College of Engineering, Nagpur
Date: July 15 - 17, 2024
Coordinators: Praveen Kumar Dhankar (G. H. Raisoni College of Engineering, Nagpur) | Surhud More (IUCAA, Pune)

Introductory Workshop on Active Galactic Nuclei and Blazars
Place: Presidency University, Kolkata
Date: July 22 - 23, 2024
Coordinators: Ritaban Chatterjee (Presidency University, Kolkata) | Vaidehi Paliya (IUCAA, Pune)

Conference on Blazars and Restless Active Galactic Nuclei (COBRA): A High Energy View
Place: Presidency University, Kolkata

Date: July 24 - 26, 2024
Coordinator: Ritaban Chatterjee (Presidency University, Kolkata) | Vaidehi Paliya (IUCAA, Pune)

Probing Stars and Galaxies using Innovative Data Science Tools
Date: September 04 - 06, 2024
Place: Department of Applied Sciences, Gauhati University
Coordinators: Eeshankur Saikia (Gauhati University) | Anupam Bhardwaj (IUCAA)

Contemporary Issues in Astronomy and Astrophysics
Date: September 13 - 15, 2024
Place: Shivaji University, Kolhapur, Maharashtra
Coordinators: Siba Prasad Das (Shivaji University) | Sanjit Mitra (IUCAA)

2nd Himalayan Meet of Astronomers (HMA) 2024
Date: September 14 - 15, 2024
Place: Central University of Himachal Pradesh, Dharamshala
Coordinators: Hum Chand (CUHP) | Naseer Iqbal (University of Kashmir, Srinagar) | Ranjeev Misra (IUCAA)

International Conference on 'Neutron star Equation Of State and Gravitational Waves' (NEOSGrav2024)
Date: October 01 - 04, 2024
Place: Goa, India
Coordinators: Debarati Chatterjee (IUCAA)

Gravitational Waves and LIGO-India
Date: October 15 - 19, 2024
Place: BITS-Pilani, Pilani Campus, Rajasthan
Coordinators: Sajal Mukherjee (BITS-Pilani) | Apratim Ganguly (IUCAA)

Workshop on Gravitation and Cosmology
Date: October 23 - 25, 2024
Place: DDU Gorakhpur University, Gorakhpur
Coordinators: Rajesh Kumar (DDU Gorakhpur University) |Shantanu Rastogi (DDU Gorakhpur University) | Apratim Ganguly (IUCAA)

North East Meet of Astronomers (NEMA) - X
Date: October 23 - 25, 2024
Place: Tezpur University
Coordinators: Rupjyoti Gogoi (Tezpur University) | Ranjeev Misra (IUCAA)

Conference on Classical and Quantum Gravity
Date: November 05 - 07, 2024
Place: Cochin University of Science and Technology, Cochin, Kerala
Coordinators: Joe Jacob (Newman College, Kerala) | Charles Jose (CUSAT, Kochi) | Dawood Kothawala (IIT, Madras)

Empowering Teachers to Foster Scientific Curiosity in Students - A Joint Initiative of STEM & Space and ARIES
Date: November 11 - 13, 2024
Place: ARIES Nainital
Coordinators: Surhud More (IUCAA)

Introductory workshop on Astronomy and Astrophysics
Date: November 13 - 15, 2024
Place: The Cochin College, Kerala
Coordinators: Sathya Narayanan (Cochin College) & Anupam Bhardwaj (IUCAA)

General Relativity: A century of observations
Date: November 21 - 23, 2024
Place: Malda College, West Bengal
Coordinators: Dr Shyam Das (Malda College) | Surhud More (IUCAA)

High Energy Astrophysics Workshop
Date: November 25 - 27, 2024
Place: Department of Physics, Banaras Hindu University, Varanasi
Coordinators: Raj Prince (BHU) & Vaidehi Paliya (IUCAA)

Introductory Workshop on Solar Astronomy
Date: November 29 - 30, 2024
Place: Patna University, Patna
Coordinators: Sumita Singh | Sanjay Kumar (Patna University) | Durgesh Tripathi (IUCAA)

IAU - Astronomy for Education Teacher Training Program 2025
Date: December 06 - 08, 2024
Place: Bishop Heber College, Tiruchirappalli, Tamil Nadu
Coordinators: Surhud More (IUCAA)

Manipal-IUCAA Astrostatistics School-2024
Date: December 10 - 15, 2024
Place: Manipal Centre for Natural Sciences (MCNS), Manipal Academy of Higher Education, Manipal
Coordinators: Debbijoy Bhattacharya (MCNS-MAHE) & Ranjeev Misra (IUCAA)

Gravity@2024
Date: December 18 - 20, 2024
Place: Cooch Behar Panchanan Barma University, Cooch Behar

Coordinators: Ranjan Sharma (Cooch Behar Panchanan Barma University) & Kanak Saha (IUCAA)

Introductory Workshop on Astronomy and Astrophysics
Date: December 18 - 20, 2024
Place: Department of Physics, Dolphin (PG) Institute of Biomedical and Natural Sciences (DIBNS), Dehradun, Uttarakhand
Coordinators: Aasheesh Raturi (DIBNS) | Anupam Bhardwaj (IUCAA)

National Conference on Data Science Innovation on Astronomy (NCDSIA)
Date: January 03 - 05, 2025
Place: Amity University, Kolkata
Coordinators: Abisa Sinha (Amity University) & Asis K. Chattopadhyay (University of Calcutta)

Focused meeting on Cosmology and Gravitation
Date: January 08 - 10, 2025
Place: Gauhati University, Assam
Coordinators: Sanjeev Kalita (Gauhati University) & Kanak Saha (IUCAA)

Radio Astronomy School
Date: January 13 - 18, 2025
Place: Fergusson College, Pune
Coordinators: Raka Dabhade (Fergusson College)
Exhibition: On the Shoulders of Giants
Date: January 15 - 16, 2025
Place: Bamboo Garden, Fergusson College, Pune
Coordinators: Raka Dabhade (Fergusson College)

Regional Astronomy Meeting X -- Research in Astronomy -- Opportunities and Challenges
Date: January 31 - February 02, 2025
Place: The Department of Physics, Cochin University of Science and Technology, Kochi
Coordinators: Joe Jacob (Newman College) | Charles Jose (CUSAT) Ranjeev Misra (IUCAA)

Workshop on Optical Astronomy
Date: February 28 - March 02, 2025
Place: The Department of Physics, St. Thomas College, Ranni
Coordinators: Joe Jacob (Newman College) | Sreeja S. Kartha (Christ University) | Ranjeev Misra (IUCAA)

Tensions and Anomalies on the Sky: Quest for New Physics at Cosmological Scales
Date: March 06 - 08, 2025
Place: Centre for Theoretical Physics, Jamia Millia Islamia
Coordinators: Anjan Ananda Sen (Jamia Millia Islamia) | Anupam Bhardwaj (IUCAA)

Workshop on Stellar Evolution and Pulsation Model
Date: March 24 - 25, 2025
Place: The Department of Physics | DDU Gorakhpur University, Gorakhpur
Coordinators: Apara Tripathi (DDUGU) | Prabhunath Prasad (DDUGU) | Anupam Bhardwaj (IUCAA)

AWARDS AND DISTINCTIONS

Anupam Bhardwaj

- Professor M. K. Vainu Bappu Gold Medal 2024 awarded by the Astronomical Society of India.

Jayant V. Narlikar

- Acharya Kanad Award 2024 from Hindu Research Foundation, Mumbai, October 20, 2024.
- Fellowship of the Breakthrough Science Society, Kolkata.

Vaidehi Paliya

- IOP Publishing awarded the top-cited publishing award to the following paper in October 2024: A Gamma-ray Emitting Collisional Ring Galaxy System in our Galactic Neighbourhood, Vaidehi S. Paliya and D. J. Saikia **The Astrophysical Journal Letters, 967, L26, 2024,** DOI: **10.3847/2041-8213/ad4999**

  AAS Nova released a scientific story for identifying the collisional-ring galaxy system, Kathryn's Wheel, as a γ-ray emitter [**https://aasnova.org/2024/08/16/monthly-roundup-rings-chains-and-bubbles/**]

Swarnim Shirke

- CSQCD Special Award for excellent presentation at CSQCD 2024 by Yukawa Institute of Theoretical Physics, Kyoto, Japan, October 2024

Durgesh Tripathi

- Young Career Award, Asia Pacific Solar Physics, 6th Asia Pacific Solar Physics Meeting, November 11 - 15, 2024, Guangzhou, China.

RESEARCH GRANTS AND FELLOWSHIPS

- **Anupam Bhardwaj**
  - PM Early Career Research Grant - Anusandhan National Research Foundation, India.
  - Team Leader, International Space Science Institute - Bern/Beijing International Team on EXPANDING Universe [https://teams.issibern.ch/expanding/].

- **Souradeep Bhattacharya**
  - DST-INSPIRE Faculty Fellowship.

- **Debarati Chatterjee**
  - Awarded the George Southgate Fellowship, University of Adelaide, Australia, 2025.

- **Subhadeep De**
  - Chanakya Doctoral Fellowship Project (2022-27), Synchronization of the optical atomic clocks located at IUCAA and IISER Pune by ultra-stable fiber optic channel.
  - VAIBHAV Fellowship (2024-27) Synergizing the trapped-ion technology with quantum information processing.

- **Samir Dhurde**
  - International Astronomical Union (OAO Grant).

- **Shasvath Kapadia**
  - DST SERB grant.

- **Ajit Kembhavi**
  - Pune Knowledge Cluster (PKC):
    - National Centre for Biological Science.
    - BASF Chemicals India grant:
    - For a mentoring and scholarship program for women in chemistry and sustainability - WEnyan.
    - A platform for Gamified Learning in Chemistry and STEM Education.
    - Lenovo India grant for Teach with Tech.
    - PKC Tree Project.

- **Ranjeev Misra**
  - ISRO Grant to set up the AstroSat Science Support Cell (ASSC).
  - DST SERB ANRF TARE Program

- **Sanjit Mitra**
  - LIGO India TDCB and DAE.
  - LIGO India SEED and DST.

- **Anupreeta More**
  - DST SERB Power (Promoting Opportunities for Women in Exploratory Research) grant.

- **Dipanjan Mukherjee**
  - Indo French Centre for the Promotion of Advanced Research (IFCPAR) Grant for the project: Resolving the impact of AGN feedback on gas and star formation through simulations and observations.
  - DST Indo Italian grant

- **Sowgat Muzahid**
  - DST grant - The Role of Gaseous Halos in Galaxy Evolution.

- **A.N. Ramaprakash**
  - DST/DAE participation grant in Thirty Metre Telescope (TMT) Project at Mauna Kea, Hawaii, USA.
  - University of Crete, Greece: Institute of Plasma Physics Crete WALOP N.
  - Infosys Foundation Grant for Resurgent Caltech – IUCAA Collaboration for Advanced Instrument Development and Scientific Discoveries.
  - University of Arizona, USA: Institute of Arizona LBT1.

- **Kanak Saha**
  - ISRO grant for the project: Exploring the Nature of Lyman Continuum Emitting Sources in the AstroSat-UV Deep Field (AUDF).

- **Dhruba J. Saikia**
  - UGC Malaviya Mission Teachers Training grant.

- **Durgesh Tripathi**
  - ISRO Solar Flares P&F.
  - Indo-German (DST-Max Planck Society) Partner Group on Coupling and Dynamics of Solar Atmosphere.

PUNE KNOWLEDGE CLUSTER

About Pune knowledge Cluster

The Pune Knowledge Cluster (PKC) is one of the six S&T clusters established by the Office of the Principal Scientific Adviser to the Government of India under The City Knowledge and Innovation Cluster Initiative (CKIC). PKC aims to create, enable and nurture a collaborative S&T ecosystem for various stakeholders, including Industry, Academia, Government, and Citizens. PKC is hosted by the Inter-University Center for Astronomy & Astrophysics (IUCAA), a UGC-supported government institution in Pune.

Since July 2022, PKC is registered as a private (not-for-profit) company – Pune Knowledge Cluster Foundation, under the section 8 of The Companies Act 2013.

Vision

The Pune Knowledge Cluster (PKC) aims to bring together academia, R & D institutions, and the Industry of Pune and its surrounding areas, to address challenging problems of the region through innovative means, using scientific knowledge and engaging highly skilled human resources.

Mission

To act as a catalyst to bring together the large talent pool present in Industry, Academia, Government, and non-Governmental organizations of Pune to brainstorm, discuss and identify projects of importance and value to the region and to execute them through collaborative efforts.

Key Achievements (since April 2024)

- PKC has mobilized INR 6.7CR for the S&T ecosystem.
- PKC managed a consortium of over 10 organizations for city level disease surveillance (genomic and environmental) of infectious diseases like COVID-19, Dengue, H1N1, H3N2 and AMR.

  Through this project:

  - 1000+ environmental and genomic samples sequenced
  - 4 research publications enabled
  - Two open-source data dashboards created for COVID-19 and AMR. The COVID-19 dashboard has been recognized by WHO as India's only dashboard for live monitoring of waste water surveillance for COVID-19 and has received 50,000 views from 90+ countries.
- PKC, in collaboration with the Pune Municipal Cooperation conducted training programs called Saksham for 792 multi-purpose health workers across 15+ talukas in Maharashtra.
- PKC conceptualized and enabled the DPR for the Pune Green Hydrogen Valley Innovation Cluster. This is a public-private partnership project enabled by PKC involving 8 industries and 3 R&D organizations. The project has received in-principle sanction.
- PKC is part of the Harit Bharat Fund initiative which aims to finance and support local organizations to restore India's landscapes (aligned with The National Mission for Green India). Through this project, 15 NGOs have been supported through grants for land restoration activities in Maharashtra, Madhya Pradesh and Chhattisgarh.
- Through the WEnyan scholarship and mentorship program for women in Maharashtra, PKC has supported 37 women across 19 districts.
- Through the Teach with Tech initiative, 359 teachers across 25 schools were trained to use digital tools in classroom teaching and learning.
- Through the ChemAmaze- STEM Gamification initiative, 42 games were developed and validated in 16 schools in India with 368 teachers and 751 students.
- As part of the Global Innovation Network Program funded by the Danish Government to promote joint collaborations between India and Denmark, PKC worked with Indian and Danish partners to promote collaborations between Indian and Danish technologies for commercialization in the water management sector.
- PKC conducted 57 training programs, conferences, workshops, talks, and networking events, collectively benefiting over 3,400+ industry professionals, students, academics, and citizens.

PKC Focus Areas

I. One Health

The One Health vertical aims at understanding the prevalence of infectious diseases in the city, by using vector dynamic and viral epidemic data, through collaborations with different stakeholders. Data is collected and analysed at the city-level to understand its correlation with outbreaks, and design better preventive measures as well as decision- making tools for the local authorities.

Projects: PKC has worked on the following projects within the last year:

1. **COVID-19 Clinical Database:**

   PKC, together with partner organizations, including hospitals, research organizations and companies has built and launched a comprehensive open-source database consisting of epidemiological, clinical and genomic data for COVID-19.

2. **Environmental surveillance through wastewater-based epidemiology:**

   PKC has helped synergize a multi-stakeholder collaboration,

including civic bodies, research organisations and private institutions, to facilitate environmental surveillance for infectious diseases in Pune. This data will help local authorities and hospitals in developing mitigation strategies as well as a predictive model, and build an early warning system for infectious diseases.

3. **Molecular surveillance for detecting bacterial pathogen sub groups and associated Anti-microbial Resistance (AMR):**

   Through this project, a molecular surveillance method has been developed for detecting bacterial pathogen sub-groups and associated antimicrobial resistance (AMR) from clinical as well as environmental samples.

4. **Saksham Workshop Series: On ground training for multipurpose healthcare workers to improve disease surveillance of vector-borne diseases**

   PKC in collaboration with the District Malaria Offices has developed a series of workshops to empower the field workers who are responsible for the surveillance of vector-borne diseases with special emphasis on dengue and chikungunya.

5. **Environmental surveillance for zoonotic diseases**

   PKC with the partner institutes is working together for environmental surveillance of zoonotic diseases including Avian Flu, Foot-mouth-Disease (FMD) and Lumpy Skin Disease

II. Environment & Energy

PKC's Environment and Energy vertical aims at protecting the environment and addressing climate change through projects that revolve around mitigating the water scarcity problems by developing decision-making tools for local authorities, restoration of degraded lands in and around the city, providing data-driven solutions for scientific management of Pune city's tree cover, and demonstrating renewable energy (green energy) models.

Projects: PKC has worked on the following projects within the last year:

1. **Urban Forestry Programs** such as ConnecTree and TreeVerse, to preserve and improve tree cover in Pune City. PKC is working to create technology platforms to automate tree census, improve citizen engagement in tree plantation and adoption and build a computational platform for carbon sink estimation.
2. **Carbon Neutral Campus:** Through this program, PKC encourages academic campuses and Industry premises to account for their Carbon emissions through efficient data collection; and imbibe practices enabling Carbon Neutrality.
   - **Water Pricing Model**: This is a collaborative study undertaken by PKC, in which real-time data from various socio-economic classes is being collected to create a water calculator for determining the cost of water and to understand if treated wastewater can be repurposed and reused effectively, specifically by the industrial sector.
   - **Pune Hydrogen Valley Innovation Cluster:** PKC worked towards developing a Hydrogen Cluster in Pune region to foster collaborations between industries and R&D organizations for developing technologies for Green Hydrogen production, storage, transport and capacity building.
   - **Land Accelerator Program – Harit Bharat Fund:** PKC is part of the Harit Bharat Fund program, which aims at providing local enterprises with capital and capacity-building assistance to carry out land restoration projects in Maharashtra, Madhya Pradesh and Chattisgarh.

III. Sustainable Mobility

PKC's Sustainable Mobility vertical aims towards addressing the rapidly growing and changing mobility requirements through scientific and technical tools, providing support for the development of sustainable solutions for carbon-neutral transportation, and integrating scientific research into transportation planning to minimize transportation- related safety hazards.

Projects: PKC has worked on the following projects within the last year:

- **Behavioural Nudges for Sustainable Transportation –** In Partnership with PMPML, this program aimed towards increasing the ridership of public transport in Pune, in order to combat traffic congestion and air pollution

IV. STEM Education & Capacity Building

The STEM Education & Capacity Building vertical aims to provide new opportunities to students, young researchers, and professionals to improve their knowledge base and acquire advanced skills through inter-disciplinary training programs & courses, citizen-science projects, citizen-centric science talks by experts, and STEM education programs. The vertical's prime focus is to bridge the knowledge gap between skills acquired through conventional education and that required by industries and research institutions.

Projects: PKC has worked on the following projects within the last year:

1. **Teach with Tech (supported by Lenovo India):** This project aims at supporting schools with digital tools for education
2. **WEnyan (supported by BASF Chemicals India):** a mentoring and scholarship program for women in chemistry and sustainability
3. **ChemAmaze/Gamified Learning in Chemistry and STEM**

Education (supported by BASF Chemicals India): which aims at building a platform for gamified tools for learning chemistry

4. **LEAD**: which aims at providing vocational exposure and networking opportunities to students and professionals through study tours, field visits, and interactions with experts from diverse knowledge-driven sectors.
5. **One Million Galaxies:** PKC's flagship citizen science initiative in which astronomy enthusiasts are encouraged to contribute towards understanding galaxy morphology. Within the last year, 188 citizens have enrolled on the platform from India & overseas and over 2000 images and 87000+ features have been analysed.

V. Waste Management (Plastic & Water):

1. **Wastewater Management:** PKC is working with industries to explore commercial use cases for treated waste water. With regards to this, a stakeholder meeting was held on 12th March 2025 for 'Energy conservation and Treated wastewater strategies for Data Centers in collaboration with NASSCOM and the Pune Hydrogen Valley'.
2. **Plastic Waste Management:** A multi-stakeholder approach was adopted to assess plastic waste generation and management practices through targeted surveys and expert consultations in the Hinjewadi Industrial Area. Collaborations and visits, including with Naturepro Creators and Gangotree Pelletizer Unit, explored practical and tech-based solutions. MoUs and mentorship efforts are also underway to build awareness and drive local initiatives.

VI. Industry Connect:

1. **Indo-Pharma Connect:** PKC, in collaboration with IPA (Indian Pharmaceutical Alliance) launched an initiative called Indo-PharmaConnect: A Platform to enable frameworks to foster industry academia collaborations in the pharmaceutical sector.
2. **h2e Microgrid Training:** H2e Systems Pvt Ltd has designed a prototype version of a microgrid and related training modules in the field of green hydrogen technologies to offer to academic institutions. PKC in collaboration with h2E organized a hands-on skilling program for faculty of science and engineering institutions, industry professionals to showcase h2e's offerings.
3. **BVK Group India Pvt. Ltd:** Facilitating industry-academia connections, identifying specific problem statements from the industry and seeking solutions through academic expertise.
4. **HNB Engineers Pvt. Ltd:** PKC with partners has designed a training program for manpower employed in STP plants: Plant operators/engineers, ITI operators, chemists and labourers.
5. **Battery storage and applications:** PKC is working with faculty and professionals in NCL, DIAT, and the battery industry to plan a stakeholder meeting to understand training requirements for the industry. This will be followed by a two-day hands-on workshop on battery applications and storage, engaging industry, academia, faculty, and scientists.
6. **Pilots for Startups enabled by PKC:** PKC was approached by Social Alpha to enable facilitation of pilots for startups in their supported cohort for urban transition and sustainability in collaboration with local governments and industries. The startup technologies have been validated by Social Alpha

List of MoUs signed in this FY:

Sr. No.	Name of the Partner Organization
1	Meghshala Trust
2	NCBS
3	Genba Sopanrao Moze College of Engineering
4	Edunet Foundation
5	CSIR-NCL
6	The Green Concept
7	Indian Institute of Technology, Bombay (IITB)
8	Kalpak Solutions
9	JSPM University Pune
10	Dr. D. Y. Patil School of Allied Health Sciences (DYPSAHS)
11	CSIR-NCL
12	Indian Plastic Institute (IPI)
13	Chase Avian Communications Pvt. Ltd.
14	Ecovrat Envirosolutions Pvt. Ltd.
15	CSIR-NCL
16	CSIR-CCMB
17	Pint of Science India
18	Social Lab Environmental Solutions Pvt. Ltd.
19	Green Concept Ecoscapes Pvt. Ltd.
20	ICGA
21	ExploreiT Nextgen Solutions Private Limited
22	Maharashtra Metro Rail Corporation Ltd. (Maha metro)
23	BASF Chemicals Pvt Ltd

Classical and Quantum Gravity

Scalar tidal response of a rotating BTZ black hole

In their recent work*, **Rajendra Prasad Bhatt** and **Chiranjeeb Singha** studied the response of a rotating BTZ black hole to the scaler tidal perturbation. They showed that the rotating BTZ black hole possesses non-vanishing tidal Love numbers. They also observed scale-dependent behaviour in the tidal response function. Moreover, they also studied the scalar tidal response of an extremal rotating BTZ black hole and a BTZ black hole with a small charge. Since static tidal Love numbers are mainly studied for black holes in 3 + 1 and higher dimensions and found to be zero, this study might also be useful in understanding the hidden symmetries of general relativity.

*Publication: **Rajendra Prasad Bhatt** and **Chiranjeeb Singha**, Scalar tidal response of a rotating BTZ black hole, J. High Energ. Phys. 11, 154 (2024); arXiv:2407.09470 [gr-qc].

Cosmology and Structure Formation

Model-agnostic basic function basis functions for the 2-point correlation function of dark matter in linear theory

Aseem Paranjape and Ravi Sheth have developed a novel machine learning (ML) framework for systematically discovering basis functions to approximate complicated non-linear functions $f(x, \theta)$ that depend on multiple parameters θ in addition to a control variable x. The ML algorithm approximates this function as $f(x, \theta) \approx \sum_{i=1}^{N} b_i(x)\, w_i(\theta)$. The basis functions $\{b_i(x)\}$ can later be used in standard least-squares fitting exercises that involve approximating $f(x, \theta)$. Using this framework, the authors have shown that the linear theory dark matter 2-point correlation function, which frequently appears in cosmological parameter inference, can be approximated with sub-percent accuracy using only 9 ML-discovered basis functions over a wide range of cosmological parameters and scales in the vicinity of the baryon acoustic oscillation (BAO) feature. For comparison, a polynomial basis of the same size and for the same configuration leads to errors nearly a factor 20 larger, while achieving even few percent-level accuracy (about thrice as bad as that achieved with the ML basis) using a polynomial basis would require polynomials of degree exceeding 17. The results are reported in arXiv:2410.21374 and the code underlying the ML framework is publicly available at https://github.com/a-paranjape/mlfundas.

Bayesian framework to infer the Hubble constant from the cross-correlation of individual gravitational wave events with galaxies

Gravitational waves (GWs) from the inspiral of binary compact objects offer a one-step measurement of the luminosity distance to the event, which is essential for the measurement of the Hubble constant, H0, which characterizes the expansion rate of the Universe. However, unlike binary neutron stars, the inspiral of binary black holes is not expected to be accompanied by electromagnetic radiation and a subsequent determination of its redshift. Consequently, independent redshift measurements of such GW events are necessary to measure H0. In a work led by PhD student **Tathagata Ghosh** together with **Surhud More** and collaborators, a novel Bayesian approach to infer H0 by measuring the overdensity of galaxies around individual binary black hole merger events in configuration space was presented. They modeled the measured overdensity of galaxies using the 3D cross-correlation between galaxies and GW events, explicitly accounting for the GW event localization uncertainty. They demonstrated the efficacy of the method with 250 simulated GW events distributed within 1 Gpc in colored Gaussian noise of Advanced LIGO and Advanced Virgo detectors operating at O4 sensitivity. The authors showed that such measurements can constrain the Hubble constant with a precision better than 8 percent (at 90 percent highest density interval).

Optical cluster cosmology with SDSS redMaPPer clusters and HSC-Y3 lensing measurements

The abundance of galaxy clusters is quite sensitive to the cosmological parameters related to the matter density of the Universe and the amplitude of initial density fluctuations present in the Universe. In research carried out together with international collaborators, **Surhud More** at IUCAA, presented cosmological constraints obtained from a blind, joint analysis of the abundance, projected clustering, and weak lensing of galaxy clusters measured from the Sloan Digital Sky Survey (SDSS) redMaPPer cluster catalog and the Hyper-Suprime Cam (HSC) Year 3 shape catalog. They presented a full-forward model for the

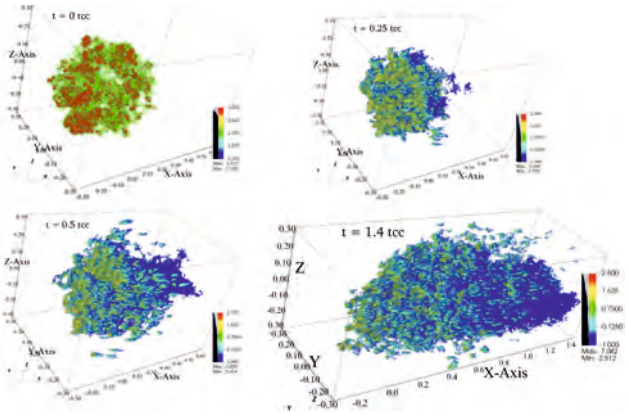


Figure 1: Volume rendering of different evolutionary stages of a gas clouds evolution due to the impact of a fast AGN driven wind from simulation GC45 of Mandal et al. 2024. The colours represent $\log(n)$, where n is the number density of the clouds. The cloud undergoes an initial phase of compression, followed by rapid ablation, which eventually leads to large-scale disruption of the cloud into smaller cloudlets and an elongated comet-like tail.

cluster observables, which includes empirical modeling for the anisotropic boosts on the lensing and clustering signals of optical clusters, a known systematic issue with optical cluster cosmology. They validate their analysis via mock cluster catalogs which include observational systematics, such as the projection effect and the effect of baryonic feedback, and showed that their analysis can robustly constrain cosmological parameters in an unbiased manner without any informative priors on model parameters. The joint analysis of their observables in the context of the flat LCDM model results in cosmological constraints for S8=$0.816-0.039^{+0.041}$. This result is consistent with the S8 inference from other cosmic microwave background-based and large-scale structure-based cosmology analyses, including the result from the Planck 2018 primary CMB analysis.

Computational Astrophysics

Probing the role of self-gravity in clouds impacted by AGN driven winds

Supermassive black holes at the centres of galaxies often generate fast winds that impact the gas of the host on a wide scale. Researchers at IUCAA have simulated the impact of such winds on dense, potentially star forming gas clouds through a suite of resolved simulations. A key inclusion in these simulations was the use of a new, in-house developed Poisson solver for the astrophysical code PLUTO. Using this novel numerical module, researchers found that the self-gravity of the clouds significantly affects the evolution of the clouds, helping them retain their shape, preventing ablation. Such conclusions were not probed earlier for such systems due to a lack of relevant numerical tools, which were implemented in this work. A representative figure of the dynamical evolution of a cloud is shown in Fig. 1. Some of the major conclusions of this study are: a) self-gravity can significantly affect cloud dynamics and prevent large scale cloud destruction, b) moderate cloud porosity helps in cloud break-up more than very low or high values, in which case the clouds get compressed into an effective dense sphere that lessens the effects of the wind-driven shocks, c) various statistical parameters related to understanding star formation have been evaluated for the suite of simulations. Such analyses indicate that the clouds go through different evolutionary stages. While the less powerful winds are unable to significantly affect the star formation rate in the core of the clouds, the more powerful winds can lead to significant cloud destruction. However, irrespective of the wind power, enhanced compression due to shocks from the winds invariably leads to a late-stage increase in star formation rate, d) the wind-cloud interaction leads to a multi-phase outflow, which can potentially explain the observed correlations between mass-outflow rates and wind power. The results have been published in the study: "Probing the role of self-gravity in clouds impacted by AGN driven winds" by Mandal et al. 2024.

A comparative study of radio signatures from winds and jets

Supermassive black holes are known to create large galactic-scale outflows of two kinds, viz., non-relativistic wide-angled winds either driven by radiation pressure or mechanical outflows from an accretion disc, or collimated relativistic jets created near the black hole's ergosphere. Both mechanisms are predicted to give rise to synchrotron radiation at shocks resulting from interaction of such outflows with their ambient medium. To unravel the distinction between the flow characteristics of these two different types of outflows and the expected difference in their emission characteristics, researchers at IUCAA have performed a large suite of simulations of both non-relativistic winds and relativistic jets, as a continuation of the study earlier reported in

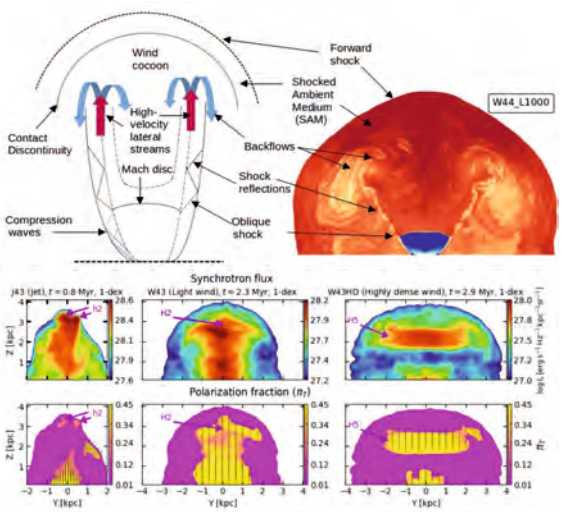


Figure 2: Top: A schematic of the internal structure of an AGN wind on the left, followed by a slice of the pressure distribution in a 3D simulation of the same confirming the predicted structures (Meenakshi et al. 2024). Bottom: A comparison of synchrotron emission (top) and polarisation (bottom) maps for a typical kpc scale relativistic jet (left) and two models of non-relativistic winds (middle and right). The maps have been convolved with a Gaussian function to represent realistic observable resolutions. The images show the clear distinction in the emission morphology between the jets and winds, which can be used as a guide to ascertain the cause of the observed radio emission in large-scale surveys.

Meenakshi et al. 2023, titled "Polarisation study of jets interacting with turbulent magnetic fields".
In the current paper, the simulation campaign was extended to include non-relativistic wind and compare the expected synchrotron emission maps of both these processes. The wind simulations show distinctly different evolution characteristics, with a wide, hemispherical forward shock sweeping the ambient medium (see top panel of Fig. 2), which is starkly different from the conical-shaped morphology of jets. Another stark difference is the dominant shock in the path of the outflows. While the jets have the strongest shocks at their head where they interact with the ambient gas, the counterpart for the winds is the termination shock close to the origin of the outflow. The results have been reported in the paper: "A comparative study of radio signatures from winds and jets: modelling synchrotron emission and polarization", Meenakshi et al. 2024.

Galactic and Extragalactic Astronomy

Environmental dependence on galaxy-halo connections for satellites using HSC weak lensing

The dense environment of galaxy clusters can affect the properties of satellite galaxies that inhabit these galaxy clusters. However, whether these effects are related to their nature or nurture within the dense environment is a challenge to establish empirically. In a research work carried out by **Amit Kumar** together with **Surhud More** at IUCAA, the luminosity-halo mass relations of satellite sLHMRs galaxies in the SDSS redMaPPer cluster catalogue and the effects of the dense cluster environment on subhalo mass evolution were studied in detail. They used data from the Subaru Hyper Suprime-Cam survey Year-3 catalogue of galaxy shapes to measure the weak lensing signal around these satellites. This signal was used to infer the masses of their associated subhalos. They binned the satellite galaxies based on observable quantities such as their luminosity or the host cluster's richness, combined with their cluster-centric radial separations. Their results show that the properties of the sLHMRs depend on the distance of the satellite from the cluster centre. Subhalos near the cluster centre (within $< 0.3h^{-1}Mpc$) are stripped of mass. Consequently, the ratio of subhalo mass to luminosity decreases near the cluster centre. For low luminosity galaxies (less than the Milky way halo mass), the lack of evidence of

increasing subhalo masses with luminosity shows the impact of tidal stripping. They also showed that the sSHMRs from the mock-redMaPPer run on galaxy catalogues generated by the empirical UniverseMachine galaxy formation model are in good agreement with their observational results.

Dark Matter Halos of Luminous Active Galactic Nuclei from Galaxy-Galaxy Lensing with the HSC Subaru Strategic Program

The connection between dark matter halos and active galactic nuclei is not entirely well understood. Together with international collaborators, **Surhud More** at IUCAA, was involved in using gravitational lensing based on imaging data from the Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP) to carry out such a program. The weak lensing signals of a sample of 48,907 AGNs constructed using HSC and Wide-field Infrared Survey Explorer photometry were utilized for this purpose. The lensing mass profile of the total AGN sample was found to be consistent with that of massive galaxies ($\log M_* \sim 10.61$). To their surprise, they also found that the lensing signal remains unchanged when the AGN sample is split into four host galaxy stellar mass bins. They found that the characteristic halo mass of the full AGN population lies near the knee of the stellar-to-halo mass relation (SHMR) at about a halo mass of $10^12 M_\odot$. The results indicate that massive halos tend to suppress AGN activity, probably due to the lack of available gas.

Detecting the invisible Circumgalactic Medium in emission

Galaxies are surrounded by diffuse haloes of multiphase gas termed the Circumgalactic Medium (CGM) that plays a crucial role in galaxy evolution by regulating the cycle of baryons in and out of galaxies. While the CGM has been extensively probed using absorption lines against a bright background source such as a quasar, this technique provides information about the CGM gas only along the pencil-beam sightline. Spatially resolved emission allows us to directly map the CGM gas, and to place more stringent constraints on the extent and physical properties of the gas, particularly when multiple line diagnostics can be obtained. However, it has been challenging in the past to probe the CGM of galaxies at cosmological distances directly using emission lines due to the low gas density. Recently, thanks to sensitive, wide-field optical integral field unit spectrographs such as the Multi-Unit Spectroscopic Explorer (MUSE) on the Very Large Telescope (VLT), it has become possible to detect the CGM directly in emission. Dutta et al., 2024 (A&A, 691A, 236) characterized, for the first time, the average extended emission in multiple lines ([O II], [O III], and Hβ) around a statistical sample of 560 galaxies at $z \approx 0.25 - 0.85$. By stacking the MUSE 3D data from two large surveys, the MUSE Analysis of Gas around Galaxies (MAGG) and the MUSE Ultra Deep Field (MUDF), significant [O II] emission is detected out to ≈ 40 kpc, while [O III] and Hβ emission is detected out to ≈ 30 kpc around galaxies. Via comparisons with the nearby average stellar continuum emission, the line emission at $20 - 30$ kpc is found to likely arise from the disk-halo interface. By comparing the observed line fluxes with photoionization models, the ionization parameter is found to decline with increasing distance from the galaxy centre, which reflects a weaker radiation field in the outer regions of galaxies. The gas-phase metallicity shows no significant variation over 30 kpc, which indicates an efficient mixing of metals on these scales. Alternatively, there could be a significant contribution from shocks and diffuse ionized gas to the line emission in the outer regions. (see Fig. 3)

JWST/NIRSpec and MIRI observations of an expanding, jet-driven bubble of warm H2 in the radio galaxy 3C 326 N

An international team of scientists, including IUCAA researchers **Dipanjan Mukherjee** and **Mayur Shende**, has observed the galaxy 3C 326N with the JWST telescope (see Fig. 4). Previous observations of the source had revealed a highly turbulent disc with a large width. It had been conjectured that the relativistic jet from the central black hole was responsible for injecting turbulence into the gas disk, leading to enhanced gas kinematics. However, the new spatially resolved observations of the system has revealed that the radio jet is driving internal, galactic-scale outflows, creating a central cavity. Such motions were misinterpreted as purely turbulent flows due to a lack of spatial resolution in earlier observations. In addition, new data of molecular CO (1-0) transitions were obtained by the team using the ALMA observatory. The combined data enabled the researchers to constrain the star formation rate of the source and compare the same with typical values of non-jetted star forming galaxies. The team found that 3C 326 is forming stars at a much lower rate than standard values, indicating a decline in star formation efficiency, despite the presence of dense, potentially star forming gas. The authors conjectured that the turbu-

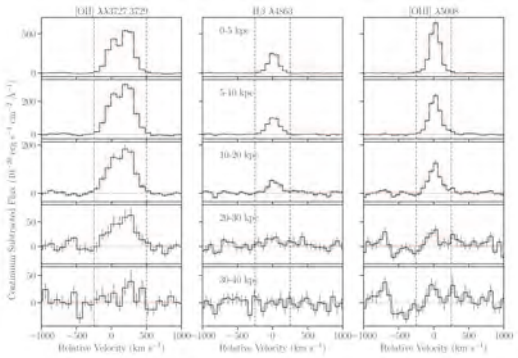


Figure 3: Stacked spectra showing the [O II], Hβ, and [O III] emission lines around galaxies in different annular regions, $0-5$ kpc, $5-10$ kpc, $10-20$ kpc, $20-30$ kpc, and $30-40$ kpc, from top to bottom. These allow us to study the spatially-resolved average physical conditions in the CGM around galaxies (Dutta et al., 2024, A& A, 691A, 236)

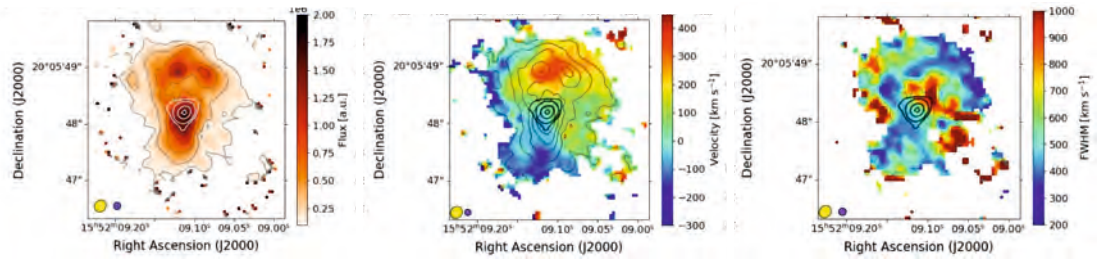


Figure 4: Observed emission (left panel) of ro-vibration lines of hydrogen (H_2 1-0 (S3)) of galaxy 3C 326 N (Leftley et al. 2024), and the velocities (middle) and line width (right), obtained using JWST. The white contours show the location of the radio core. The emission map clearly show a cavity being cleared by the jet, with bright knots at the rim due to swept up gas.

lence from the radio jet is the likely cause of such negative feedback, as also predicted by previous results from IUCAA scientists (Mandal et al. 2021). The results have been presented in the paper titled "JWST/NIRSpec and MIRI observations of an expanding, jet-driven bubble of warm H2 in the radio galaxy 3C 326 N" by Leftley et al. 2024.

Cold gas bubble inflated by a low-luminosity radio jet

An international team of scientists, including IUCAA researcher **Dipanjan Mukherjee**, has observed both halves of an expanding shell of cold molecular gas driven by a relativistic jet. Previous observations of the source had confirmed the outflowing component moving towards the observing telescopes (blue-shifted), confirming strong interaction of the jet with the host's ISM (Murthy et al. 2021). In a new set of more sensitive observations with the NOEMA telescope in the D configuration, the researchers detected the other half of the expanding shell moving away from the observer (red-shifted), indicated by the positive signatures in the position-velocity diagrams. The results were confirmed from relativistic hydrodynamic simulations of jets inclined to a gas disk, carried out earlier by **Dipanjan Mukherjee** et al. 2018. In a fresh analysis of the simulated results, the authors showed that confined jets tend to push out gas away from their axes, as they ploughs through the ISM. Such a scenario is expected to manifest as both blue and red-shifted line observations when viewed at certain orientations. The observed results thus confirm the long-standing predictions of theoretical simulations regarding active interaction of jets with the host's ISM, creating large-scale outflows within the gas disk of the host galaxy. The results have been published in the paper titled "Cold gas bubble inflated by a low-luminosity radio jet" by Murthy et al. 2025. (see Fig. 5)

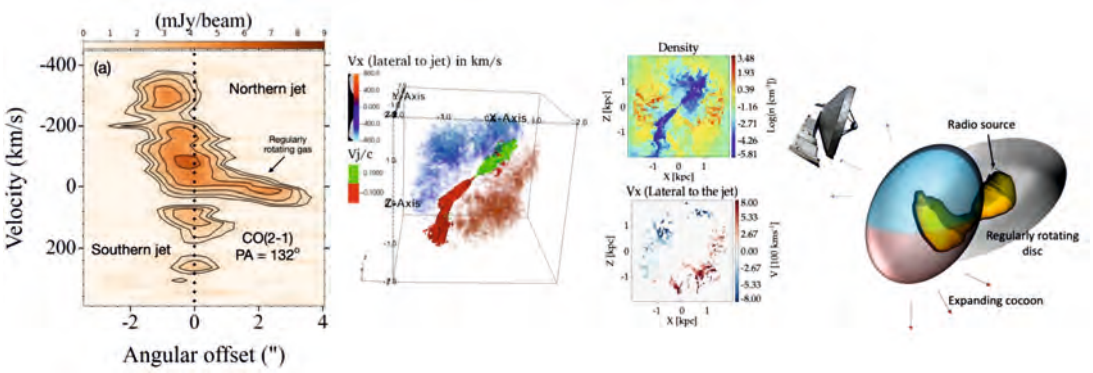


Figure 5: Left: Position-velocity (PV) diagram depicting gas kinematics along the radio jet of B2 0258+35 (Murthy et al. 2025). The PV plot clearly shows both blue shifted and newly detected red-shifted components of an expanding shell of gas driven by the radio jet. Right: Comparison of the observed results with results from relativistic hydrodynamic simulations of jet-ISM interaction.

Disocvery of a cosmic web filament from 11.7 billion years ago

Cosmic web filaments are fundamental predictions of modern cosmological hydrodynamical simulations based on the Lambda Cold Dark Matter model, which is the most robust framework for understanding the cosmic evolution of the universe. However, directly detecting these filaments has proven to be exceptionally challenging due to their extremely low densities. Identifying such tenuous and filamentary structures remains one of the most significant challenges in observational astrophysics. With the advent of state-of-the-art integral field spectroscopy (IFS), it is now possible to investigate cosmic filaments around massive objects such as quasars with unprecedented precision. The IFS technique enables astronomers not only to target specific regions of the sky where such filaments are likely to exist but also to focus on the precise wavelength range where the expected emission signal can be detected. A team of IUCAA researchers have discovered a giant cosmic web filament stretching nearly 850,000 light-years by analyzing light emitted 11.7 billion years ago (see Fig. 6). This filament is connecting seven Lyman-alpha emitting galaxies. To put this in perspective, this length is roughly 10 times the size of the Milky Way's stellar disk and one-third of the distance between the Milky Way and our nearest neighbor, Andromeda. The discovery was made possible using the VLT/MUSE IFS instrument. The filament is the first of its kind for which they could successfully constrain the metallicity of the gas using complementary absorption line techniques, revealing its primordial nature. Additionally, in contrast to previously known systems, none of the seven galaxies linked to the filament show any evidence of quasar-like properties. The search for these elusive structures and the detailed characterization of their properties will stand as one of the foremost scientific objectives in the era of next-generation 30-meter-class telescopes. This discovery represents a pivotal first step toward this transformative exploration, laying the groundwork for future breakthroughs in this field

AstroSat UV Deep Field South. I. Far and Near-Ultraviolet Source

The AstroSat UV Deep Field (AUDF) is an imaging survey carried out with the wide-field UltraViolet Imaging Telescope (UVIT) on AstroSat in two broad bands — F154W (1300–1800 Å) and N242W (2000–3000Å). AUDF South (PI: **Kanak Saha**) covers ∼236 arcmin^2 of the sky area, including the Great Observatories Origins Deep Survey (GOODS) South field. These observations (e.g. see Fig. 7) reached a 3σ depth of 27.2 and 27.7 AB mag with a 50% completeness limit of 27 and 27.6 AB mag in the F154W and N242W filters, respectively, in about 63000 sec of exposure time. A similar imaging survey called the AstroSat UV Deep Field North was carried out centered on the GOODS North field in three filters, namely, F154W (34000 sec), N245M (15500 sec) and N242W (19200 sec) of UVIT. AUDF North (PI: Kanak Saha) reached a 3σ depth of about 27 AB mag (see Mondal+2023, ApJS). With the acquired depth, AUDF South and North are the deepest far- and near-UV imaging data, covering the largest area known to-date

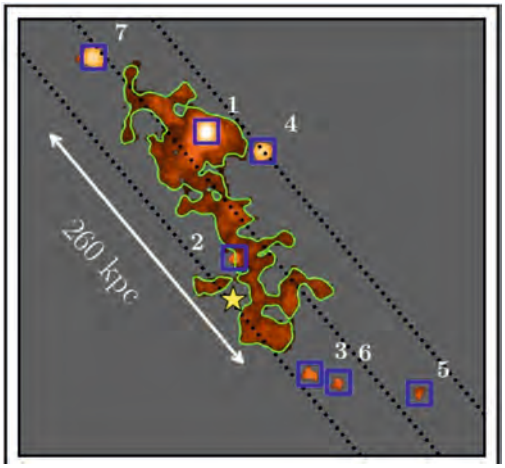


Figure 6: Left: The seven galaxies, highlighted in blue boxes, detected with MUSE exhibit a striking linear alignment, indicating an underlying filamentary structure. This alignment is remarkably mirrored by a 260-kpc-long Lyman-alpha nebula emanating from the giant filament. The yellow star pinpoints the location of the background quasar, whose light served as a probe to measure the metallicity of the filament, confirming its primordial nature.

at 1.2–1.6 arcsec spatial resolution. Two primary catalogs were constructed for the F154W and N242W filters, each containing 13495 and 19374 sources brighter than the 3α detection limit, respectively. The galaxy counts distribution defined with a power-law slope of $\sim$0.43 dex/mag in the N242W filter matches well with Hubble Space Telescope/Wide-Field Camera 3/UVIS observations. A wide range of extragalactic science can be achieved with this unique data, such as providing a sample of galaxies emitting ionizing photons in the redshift range of $z \sim 1-3$ and beyond, constraining the UV luminosity function, investigating the extended UV emission around star-forming galaxies and UV morphologies for $z < 1$. The UV catalog will enhance the legacy value of the existing optical/IR imaging and spectroscopic observations from ground- and space-based telescopes on the GOODS South field. This work has been published in Astrophysical Journal Supplementary Series, 2024, Vol. 275, p.28. (Saha+2024, ApJS).

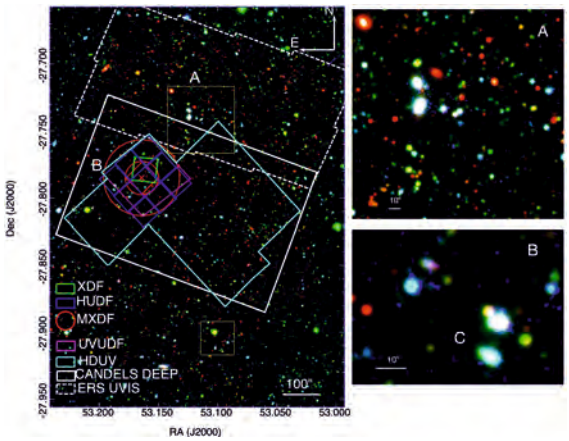


Figure 7: Left: False colour RGB image of the AstroSat UV Deep Field South. Red, Green, and blue filters used to create the image are HST/WFC/F606W, UVIT/N242W and UVIT/F154W. All three images are PSF matched and at the same pixel scale. Zoomed-in regions show the quality and astrometry of the UVIT Deep field images.

A million radio sources seen by MeerKAT probes the motion of the solar system and provides a fundamental test of cosmology

The second data release from the MeerKAT Absorption Line Survey (MALS)

Using data from the MeerKAT radio telescope, an international team of astronomers from the MeerKAT Absorption Line Survey (MALS; https://mals.iucaa.in) collaboration has released a million-source catalog. This is the largest catalog produced by a MeerKAT survey thus far, one of only a handful of radio catalogs with a million or more sources. The MALS team has used this catalog to test the cosmic dipole effect which makes sources appear brighter in one portion of the sky than the other (Figure 8). While many other measurements in the past 10 years have disagreed with the original measurement based on the CMBR, the MALS team's findings are consistent with the prediction, a surprising result in itself. Measuring the dipole is an extremely important test of cosmology, and can tell us whether our fundamental assumptions about the structure of the Universe are correct. To get to these deep images from the large amounts of raw data produced by MeerKAT, a sophisticated processing pipeline and data storage facility have been set up

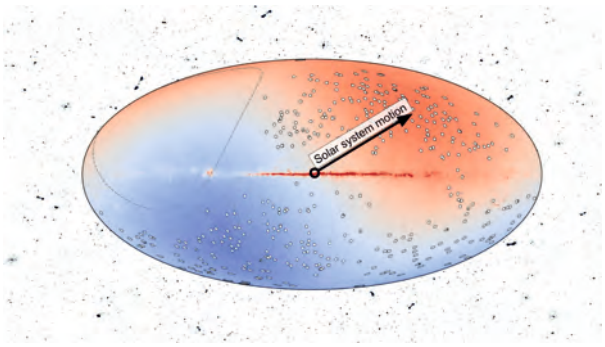


Figure 8: A map of the sky overlaid on a portion of single MeerKAT pointing containing a few thousand radio sources. In the sky map, circles mark positions of 391 pointings containing a total of 971,980 sources. The arrow shows the direction of the cosmic dipole originally established by measurements of the cosmic microwave background radiation (CMBR). The dipole effect will make the sources appear more numerous (red portion) in the direction of the motion and less in the opposite direction (blue portion).

at the Inter-University Centre for Astronomy and Astrophysics (IUCAA) in India. The images and catalogs were analyzed and prepared for public release at the Max Planck Institute for Radio Astronomy (MPIfR) in Germany. The depth and the expanse of this continuum catalog holds a unique position among modern radio continuum surveys. The public release will enable the community to address a wide range of issues associated with the evolution of galaxies and the Universe. Due to its focus on depth rather than sky coverage, many sources in MALS images have been detected for the first time, undoubtedly influencing the dipole measurement. The mystery, however, is far from resolved, and future larger catalogs, either from MALS using the lower frequency UHF band of MeerKAT, or future observatories, will have to dissect these findings and resolve the tension. The consistent and automated processing was essential to have a good handle on subtle effects in the data which would adversely affect the accuracy of our measurements. This new survey is the stepping stone for future large-scale radio surveys, with the Square Kilometre Array and Deep Synoptic Array. The new catalog and accompanying scientific results of this study are described in Wagenveld et al. (2024), accepted for publication in Astronomy & Astrophysics. This is the second of several radio continuum and spectral line data releases to come from MALS, and making this data release has been a team effort. The MALS catalogs and images are publicly available at https://mals.iucaa.in. The MALS team is an international collaboration of researchers from around the world. The project is led by **N. Gupta** from IUCAA, India. The MeerKAT telescope is a facility of the National Research Foundation (NRF) in South Africa and is operated by the South African Radio Astronomy Observatory (SARAO).

Gravitational Waves and Gravitational Lensing

Improved binary black hole searches through better discrimination against noise transients.

Work by S. Choudhary, T. Ghosh, S. Bose, **S. Dhurandhar** and P. Joshi. The short-duration noise transients in LIGO and Virgo detectors significantly affect the search sensitivity of compact binary coalescence (CBC) signals, especially in the high mass region. In the previous work by the authors a chi-squared statistic was proposed to distinguish them from CBCs. This work is an extension of the improved noise-discrimination of the optimal chi-squraed statistic in real LIGO data. The tuning of the optimal chi-squared statistic includes accounting for the phase of the CBC signal and a well-informed choice of sine-Gaussian basis vectors. This allows one to discern how CBC signals and some of the most worrisome noise transients project differently. Real blip glitches (a type of short-duration noise disturbance) are considered from the second observational (O2) run of LIGO-Hanford and LIGO-Livingston detectors. The binary black hole signals were simulated using IMRPhenomPv2 waveform and injected into real LIGO data from the same run. It is shown that in comparison to the traditional chi-squared and the sine-Gaussian chi squared, the optimal chi squared improves the signal detection rate remarkably.

Improved Binary Black Hole Search Discriminator from the Singular Value Decomposition of Non-Gaussian Noise Transients

Work by **Tathagata Ghosh**, Sukanta Bose, **Sanjeev Dhurandhar** and Sunil Choudhary. The sensitivity of the transient gravitational wave signal is significantly affected by the blip glitches. Blip glitches are short-duration noise transients that resemble the waveform of massive binary black holes. In earlier works, optimal choices of the sine-Gaussian waveform

as a set of basis vectors were employed to construct the chi-square. This construction was based on the unified formalism of chi-square to discriminate against blip glitches while searching for the compact binary coalescence (CBC) signals. This work explores the prospects of constructing the chi-square from the blip glitches that occur in the detector data. A detailed methodology for constructing the chi-square from the real glitch data is presented. We find that the chi-square developed in this work performs as efficiently as the optimal chi-square.

A χ^2 statistic for the identification of strongly lensed gravitational waves from compact binary coalescences

Gravitational waves (GWs) emanated by stellar mass compact binary coalescences (CBCs), and lensed by galaxy- or cluster-scale lenses, will produce two or more copies of the GW signal. These will have identical phase evolution but differing amplitudes. Such lensing signatures are expected to be detected by the end of the LIGO-Virgo-Kagra's (LVK's) fifth observing run (O5). In this work, **Sudhir Gholap, Kanchan Soni, Shasvath Kapadia** and **Sanjeev Dhurandhar** propose a novel $\chi^2_{\rm lens}$ statistic to segregate pairs of detected GW events as either lensed or unlensed (shown in Fig. 9), using templates typically used in GW searches. The statistic is an application of the generalized χ^2 discriminator described in **S. Dhurandhar** [2017], tailored to probe the similarity (or lack thereof) between the phase evolutions of two CBC signals. Authors assess the performance of $\chi^2_{\rm lens}$ on a realistic astrophysical dataset of lensed and unlensed CBCs detectable in O4, assuming a single LIGO-like detector at design sensitivity. Authors find that this method can correctly identify lensed events with efficiencies comparable to existing Bayesian and machine learning methods. Evaluating $\chi^2_{\rm lens}$ is orders of magnitude faster than Bayesian methods. Moreover, the statistics of $\chi^2_{\rm lens}$, in stationary Gaussian noise, are fully understood, in contrast to machine learning methods. $\chi^2_{\rm lens}$ can, therefore, be used to rapidly and accurately weed out the vast majority of unlensed candidate pairs and identify lensed pairs.

Detectability of eccentric binary black holes with ground-based gravitational wave detectors

In the first ten years of gravitational wave astronomy nearly hundred compact binary coalescences have been observed and about two hundred detection candidates have been identified in the ongoing fourth observing run. While this is a great beginning, the predominant formation channel for the binaries is yet to be identified. If the binaries are formed through the dynamical formation channel in dense star clusters, as opposed to isolated evolution, the binaries should exhibit significant residual trace of eccentricity. **Kanchan Soni** and **Sanjit Mitra**, along with other collaborators, show that the present searches for binaries, which assume quasi-circular orbit ignoring eccentricity to reduce computation cost and lack of reliable templates, have substantially less sensitivity to detect the eccentric sources. Their study highlights the need for the development of a dedicated matched-filter search for these binaries with the associated template bank, neglecting which will bias the estimation of chirp mass, mass ratio, and effective spin parameter, skewing our understanding of astrophysical BBH populations, fundamental physics, and precision cosmology.

Rotating black holes experience dynamical tides

In their recent work [Phys. Rev. D 111, L041504 (2025); arXiv:2406.09543 [gr-qc]], **Rajendra Prasad Bhatt**, Sumanta Chakraborty, and Sukanta Bose calculated the dynamical tidal response of a Kerr black hole. They also showed that the tidal Love numbers of Kerr black holes are non-vanishing when present in a non-axisymmetric external tidal field. To leading order, they depend on the black hole spin and linearly on mode frequency. It implies that Kerr black holes are deformable under certain external, time dependent perturbations. Since non-vanishing tidal Love numbers are used in compact binary coalescence observed by the LIGO-Virgo-KAGRA Collaboration to infer their non-black hole nature, their findings have important implications on such inferences from future gravitational wave observations.

Publication: **Rajendra Prasad Bhatt**, Sumanta Chakraborty, and Sukanta Bose, Rotating black holes experience dynamical tides, Phys. Rev. D 111, L041504 (2025); arXiv:2406.09543 [gr-qc].

Study of unstable oscillation modes in Neutron Stars

Unstable oscillation modes in neutron stars can be important sources of GW, not only in binary systems but also isolated stars. With the increasing sensitivity

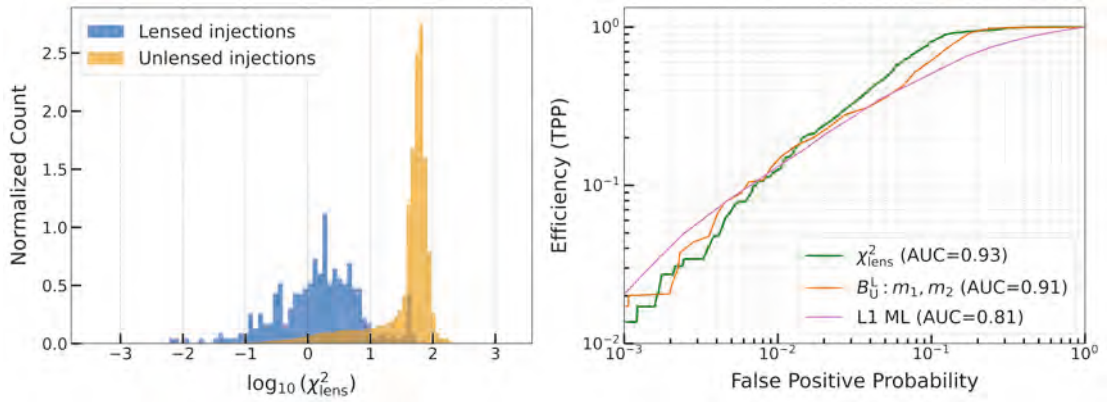


Figure 9: (Left) The histograms of $\log_{10}\left(\chi^2_{\rm lens}\right)$ computed for lensed and unlensed signals for an astrophysical population having 300 lensed and half a million unlensed pairs. (Right) ROC curves for $\chi^2_{\rm lens}$ statistic (green), the m_1, m_2 $B^{\rm L}_{\rm U}$ statistic (orange) from Haris [2018] and single detector machine learning classifier (pink) from Goyal [2021]. Area under the curve (AUC) is presented as the performance metric.

of the current GW detectors (A+) or with the next-generation detectors such as Einstein Telescope (ET), Cosmic Explorer (CE), and the Neutron Star Extreme Matter Observatory (NEMO), NS stellar oscillation modes could be detectable, which may provide an excellent opportunity to investigate its complex interior. **Debarati Chatterjee**, along with PhD student **Bikram K. Pradhan** and postdoctoral student **Dhruv Pathak**, demonstrated within a Bayesian formalism how future f-mode observations can be used to constrain the nuclear parameters and NS interior composition using inverse NS asteroseismology (Pradhan et al. (2023) ApJ 956, 38). This study was also extended to binary NS (BNS) systems, in collaboration with IUCAA PhD student **Tathagata Ghosh**.

In this work, any possible bias in the inference of nuclear parameters resulting from the ignorance of higher-order f-mode dynamical tidal corrections in the gravitational waveform model was investigated (Pradhan et al. (2024) ApJ 966, 79). Depending on the type of hadron-quark phase transition, one may expect a third family of stable compact stars or "twin stars" to appear, with the same mass but different radii compared to NSs. In (Pradhan et al. (2024) MNRAS 531, 4640), the potential of probing the nature of the hadron-quark phase transition through future gravitational wave (GW) detections from f-mode oscillations in Neutron Stars was investigated. Dark Matter (DM) is about five times as prevalent as ordinary nuclear matter, ranging from astrophysical observations (dwarf galaxies rotation curves or the mass distribution of the Bullet cluster) to cosmological observations (structure formation and the cosmic microwave background). However, the particle nature of DM is still unknown. It is conjectured that DM could also be present in NSs, accreted into their interiors, forming a DM core or as DM halo beyond their radius. Large DM fractions can be realized in NSs via a novel mechanism of neutron dark decay. If DM exists in NSs, it could affect GW emission through its effects on global NS properties such as its mass and radius, or its effect on unstable oscillation modes such as f-modes. The effect of DM on f-mode oscillations in DM-admixed NSs was investigated in (Shirke et al. (2024) Phys. Rev. D 110, 063025) highlighting the importance of accounting for degeneracy with DM models while constraining the NS equation of state with future observations. Universal relations were obtained for the DM fraction based on the total mass (M) of the star and DM self-interaction strength (G) (Fig. 10), connecting macroscopic observables to microscopic quantities. Although neutron stars can, in general, be assumed to be cold, in astrophysical scenarios such as newly born neutron stars or remnants of binary neutron star mergers, finite temperature effects play a non-negligible role. In (Barman et. al. (2025) Phys. Rev. D 111), a consistent and systematic investigation of the role of nuclear parameters and thermal effects on neutron star properties and f-modes was performed within a full general relativistic scheme.

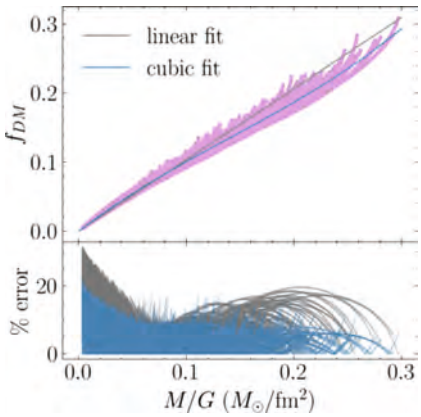


Figure 10: Top: the DM fraction (fDM) as a function of M/G obtained by varying all the microscopic parameters. The gray and blue lines are linear and cubic fits, respectively. Bottom: the percent error for the two fits.

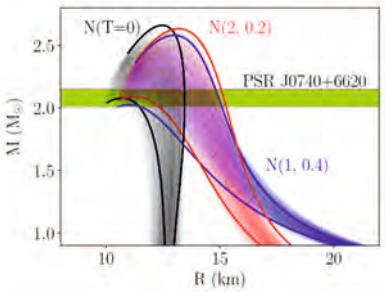


Figure 11: Posterior distributions of masses and radii of cold (black) and hot (coloured) NS configurations for nucleonic matter (N) in the core. The figure shows two hot NS configurations described by two thermal states of the star, denoted by their entropy (S/A) and charge fraction (Y_Q): $N(S/A = 1, Y_Q = 0.4)$ (in blue) and $N(S/A = 2, Y_Q = 0.2)$ (in red). The distributions are compatible with constraints from microscopic calculations of nuclear matter and astrophysical observations.

Transport properties in Neutron Stars and their role in Gravitational Wave emission

Viscous processes in NS matter during a binary inspiral can damp out the tidal energy induced by the companion and heat up the star. Previous investigations concluded that this tidal heating is negligible for normal NS matter. In (Ghosh et al. (2024) Phys. Rev. D 109, 103036), a novel effect of tidal heating involving strange matter in the NS interior was suggested, which can significantly heat up the star, and is potentially observable by current and future gravitational wave detectors. It was proposed that this could serve as a direct probe of strangeness in neutron stars. In collaboration with Max Planck Institute of Gravitational Physics, Potsdam, Germany, in (Saketh et al. (2024) Phys. Rev. D 110, 103001), a scattering amplitude formalism was presented to study the tidal heating effects of non-spinning neutron stars, incorporating both world line effective field theory and relativistic stellar perturbation theory.

Profiling stellar environments of gravitational wave sources

Gravitational waves (GWs) have enabled direct detections of compact binary coalescences (CBCs). However, their poor sky localisation and the typical lack of observable electromagnetic (EM) counterparts make it difficult to confidently identify their hosts, and study the environments that nurture their evolution. In this work, we show that *detailed* information of the host environment (e.g. the mass and steepness of the host potential) can be directly inferred by measuring the kinematic parameters (acceleration and its time-derivatives) of the binary's center of mass using GWs alone, without requiring an EM counterpart.

We consider CBCs in various realistic environments such as globular clusters, nuclear star clusters, and active galactic nuclei disks to demonstrate how orbit and environment parameters can be extracted for CBCs detectable by ground- and space-based observatories, including the LIGO detector at A+ sensitivity, Einstein Telescope of the XG network, LISA, and DECIGO, *on a single-event basis*. These constraints on host stellar environments promise to shed light on our understanding of how CBCs form, evolve, and merge.

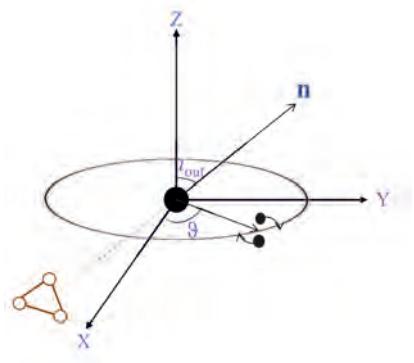


Figure 12: A schematic representation of a binary orbiting around an SMBH (or, any center of potential) in a circular orbit. Here, $\iota_{\rm out}$ is the angle between our LOS $\boldsymbol{n}$ and the angular momentum vector of the outer orbit, which is along $\boldsymbol{e}_z$.

Shasvath Kapadia is also **Gopalkrishna Prabhu's** principal supervisor. With collaborators at ICTS-TIFR, they are probing the abundance of compact objects, and their properties, in our Milky Way galaxy using the non-detection of continuous gravitational waves. This work has resulted in one publication in ApJ, and another work is in preparation. Moreover, they are also working on constructing a framework to constrain the spin of a spinning lens using gravitational lensing of GWs that exhibits wave-optics effects. **Shasvath Kapadia** is **Sudhir Gholap's** principal supervisor. In collaboration with **Sanjeev Dhurandhar**, they are working on a project involving the identification of strongly lensed gravitational waves using template banks. This work is now posted to arXiv and is under review in PRD.

High Energy Astrophysics

Accretion Geometry of GX 339-4 in the Hard State: AstroSat View

Swadesh Chand and **Gulab C. Dewangan** performed broadband ($0.7 - 100$ keV) spectral analysis of five hard state observations of the low-mass black hole X-ray binary GX∼339-4 taken by AstroSat during the rising phase of three outbursts from 2019 to 2022. They found that the outburst in 2021 was the only successful full outburst, while the source was unable to transition to the soft state during the other two outbursts in 2019 and 2022. Their spectral analysis employs two different model combinations, requiring two separate Comptonizing regions and their associated reflection components and soft X-ray excess emission. The harder Comptonizing component dominates the overall bolometric luminosity, while the softer one remains relatively weak. Their spectral fits indicate that the disk evolves with the source luminosity, where the inner disk radius decreases with increasing luminosity. However, the disk remains substantially truncated throughout all the observations for source luminosity between $\sim 2\% - 8\%$ of the Eddington luminosity. They note that their assumption of the soft X-ray excess emission as disk blackbody may not be realistic, and this kind of soft excess may arise due to the inhomogeneity in the disk/corona geometry. Their temporal analysis, deriving the power density spectra, suggests that the break frequency increases with the source luminosity. Furthermore, their analysis demonstrates a consistency between the inner disk radii estimated from the break frequency of the power density spectra and those obtained from the reflection modeling, supporting the truncated disk geometry in the hard state. This part of the work has been published in The Astrophysical Journal (ApJ) [Chand et al. 2024].

Novel observations of a Tidal Distruption Event (TDE)

An international team involving **Gulab C. Dewangan** from IUCAA used NASA and ISRO missions to observe a rare and dramatic cosmic event where a massive black hole, after tearing apart a star in 2019, created a disk of stellar debris that has since expanded and is now colliding with another nearby object possibly a star or a stellar-mass black hole, orbiting the larger black hole. This interaction causes bursts of X-rays every ∼48 hours as the orbiting object plunges through the debris disk, much like a diver repeatedly splashing into a pool. Detected using NASAs Chandra, Hubble, NICER, and Swift telescopes, along with India's AstroSat, this event, AT2019qiz, provides the first direct connection between tidal disruption events (TDEs), where stars are torn apart by black holes, and quasi-periodic eruptions (QPEs), mysterious repeating X-ray flares. The discovery reveals that these eruptions only begin a few years after a tidal disruption, once the debris disk grows large enough to intersect the orbit of another object. This breakthrough enhances our understanding of the dynamics around supermassive black holes and could aid future searches for gravitational wave sources.

ASTROSAT observations of NGC 4151

Gulab C. Dewangan and his PhD student **Shrabani Kumar** led a study where they analyzed five sets of simultaneous AstroSat observations of the active galaxy NGC 4151, covering near-ultraviolet (NUV) to hard X-rays (∼0.005–80 keV) taken between 2017 and 2018. After accounting for extinction and other emissions, the intrinsic radiation from the accretion disk was extracted, revealing a bluer UV continuum when the galaxy was brighter. This could be due to changes in the disk or the amount of UV reddening. Using earlier Hubble data, the intrinsic reddening was estimated as E(B-V) ∼ 0.4. The X-ray spectra were modeled using components like thermal Comptonization, absorption, and reflection, revealing much higher X-ray absorption than expected from UV measurements. To explain this, two models are proposed: one with separate dusty and dust-free layers divided by the dust sublimation radius, and another with dense clouds in a diffuse medium, where the X-rays are blocked by clouds, but the UV light mostly passes through. Additionally, a link was observed between stronger X-ray absorption and changes in UV brightness and color, suggesting stronger winds could be triggered by the brighter, bluer UV light.

2017 Outburst of H 1743–322: AstroSat and Swift View

In a collaborative effort, Guru Ghasidas Vishwavidyalaya (P. Sahu, P. Thakur and S. Das), IUCAA **(Swadesh Chand, Gulab C. Dewangan)**, ISRO (Vivek Agrawal), and Chattisgarh State Forensic Science Laboratory (Prakash Tripathi) performed a temporal and wide-band spectral study of black hole X-ray binary H 1743-322 using observations from AstroSat and Swift/XRT during the 2017 outburst. The study revealed that, unlike the successful outburst in 2016, the 2017 event was a "failed outburst," where the source didn't transition to a soft state. A type-C quasi-periodic oscillation (QPO) at ∼0.4 Hz was detected in both AstroSat and Swift/XRT data, with a higher harmonic at ∼0.9 Hz seen only in AstroSat. A small frequency shift (∼0.08 Hz) occurred over three days. Comparing the failed outbursts of 2017 and 2018, soft time lags (where lower-energy X-rays arrive later) were found at the QPO frequencies in both years, possibly linked to reflection from the accretion disk. Spectral modeling shows the source remained in a low/hard state, with a truncated accretion disk located at least 27.4 gravitational radii away from the black hole, while the system's luminosity was only ∼1.6% of the Eddington limit. This part of the work has been published in The Astrophysical Journal (ApJ) [Sahu et al. 2024].

UVIT observations of IC 43292A

Piyali Ganguli, Gulab C. Dewangan, and **Priyanka Rani** used high-resolution images from AstroSat's Ultra-Violet Imaging Telescope (UVIT) to study the area around the Seyfert galaxy IC 4329A in both near- and far-ultraviolet light. These observations, taken over five sessions, represent the deepest UV images of this region so far, with very sensitive detection limits (NUV magnitude 26.2 and FUV magnitude 25.7). Thanks to UVIT's sharp imaging capability, Ganguli et al. identified 4,437 sources in the NUV and 456 in the FUV, many of which had not been seen before. They measured the exact positions and brightness of all these sources. By comparing the UVIT sources with those in Gaia and XMM-Newton catalogues, the team found matches for 651 optical and 97 X-ray sources. They also discovered 28 ultraviolet sources that vary in brightness, with three showing changes in both NUV and FUV bands. Additionally, based on their UV and optical properties, it was found that two objects previously classified as white dwarfs were likely misidentified. Some galaxies in the UVIT images show unusual shapes, like rings, multiple bright centres, or split spiral arms. Further optical and multi-wavelength observations are needed to better understand these intriguing objects.

What Is the Black Hole Spin in Cyg X–1?

An international team including IUCAA members and **Gulab C. Dewangan** performed a detailed study of the black hole spin of Cyg X–1, by using accurate broadband X-ray data obtained in the soft spectral state by simultaneous NICER and NuSTAR observations, supplemented at high energies by INTEGRAL data. They used the relativistic disk model `kerrbb` together with different models of the Comptonization high-energy tail and the relativistically broadened reflection features. Unlike most previous studies, we tie the spin parameters of the disk and relativistic broadening models, thus combining the continuum and reflection methods of spin determination. They also considered a likely increase in the disk color correction due to a partial support of the disk by large-scale magnetic fields. We find that such models yield a spin parameter of $a_* = 0.87^{+0.04}_{-0.03}$ if the

disk inclination is allowed to be free, with $i = 39° \pm 1°$. Assuming $i = 27.°5$, as determined by optical studies of the binary, worsens the fit but leads to similar values of the spin, $a_* = 0.90^{+0.01}_{-0.01}$. In addition, the presence of a warm Comptonization layer on top of the disk was modelled, motivated by successful modeling of soft X-ray excesses in other sources with such a model. This dramatically lowers the spin, to $a_* \leq 0.1$, consistent with the spin measurements from black hole mergers. On the other hand, if the natal spin of Cyg X-1 was low but now $a_* \approx 0.9$, a period of effective supercritical accretion had to take place in the past. Such accretion could be facilitated by photon advection, as proposed for ultraluminous X-ray sources. This work has been published in The Astrophysical Journal Letters (ApJL) [Zdziarski et al. 2024].

A Gamma-ray-emitting Collisional Ring Galaxy System in Our Galactic Neighborhood

IUCAA scientists led by **Vaidehi Paliya** identified a γ-ray emitting collisional ring galaxy system, known as Katheryn's Wheel, located at a mere 10 Mpc distance while searching for the potential counterpart of unassociated γ-ray sources. This enigmatic system is similar to a Cartwheel galaxy, where a small, bullet galaxy pierces through the central region of a larger galaxy, leaving behind a ring of star-forming regions. The findings were published in the Astrophysical Journal Letters and were the subject of an IUCAA press release and an AAS Nova story.

Radio Morphology of Gamma-ray Sources

With the advent of wide-field, sensitive radio surveys covering both GHz and MHz frequencies, e.g., VLASS and LOFAR, **Vaidehi Paliya** carried out a systematic search of γ-ray detected misaligned radio sources, i.e., AGNs whose jet viewing angle is expected to be large (>10 deg.). Since the γ-ray emission strongly depends on the viewing angle due to Doppler boosting effects, this project may pave the way to explore the radiative processes (leptonic/hadronic) responsible for the observed γ-ray emission from AGNs. 149 γ-ray emitting misaligned jetted AGNs were identified, increasing the sample size of such objects by three. This catalog has been published in the Astrophysical Journal.

Narrow-line Seyfert 1 (NLSy1) galaxies in the wide-field sky surveys

NLSy1 galaxies are rapidly accreting AGNs powered by low-mass black holes, and some of them are found to host relativistic jets. Using the multiwavelength data made available by the current generation of all-sky surveys, e.g., SDSS-DR17, VLASS, LOFAR, e-ROSITA, and Fermi-LAT, **Vaidehi Paliya** has started a project to carry out a broadband study of NLSy1 sources. In the first step, >2 million SDSS spectra (classified as either QSO or Galaxies) were analyzed to prepare a new catalog of bona fide NLSy1 galaxies. This catalog has been published in the MNRAS journal.

DA 362: A Gamma-Ray-emitting Compact Symmetric Object

Subhashree Swain and collaborators, including **Vaidehi Paliya**, carried out a multiwavelength study of the radio source DA 362, which was reported to be a blazar candidate of uncertain type. However, it was recently identified as a bona fide Compact Symmetric Object (CSO) based on its sub-kiloparsec, bipolar radio morphology, and lack of radio variability. This makes DA 362 only the fourth gamma-ray-emitting object of this enigmatic class of radio-loud AGNs. Using five very-long-baseline interferometry observations covering 1996–2018, the jet separation velocity is found to be subluminal (vapp $\sim$ 0.2c), thus supporting its CSO nature. Its Fermi-LAT observations revealed a γ-ray flaring activity, a phenomenon never detected from the other three γ-ray-detected CSOs. This object is bright in the near-infrared band but extremely faint in the optical-UV filters, hinting at possible obscuration.

Quantum Technologies

Precision & Quantum Measurement laboratory

The Precision & Quantum Measurement Laboratory (PQM-lab) is involved in (i) setting-up of a ytterbium-ion based optical atomic clock experiment (quantum clock) for fundamental science test, and (ii) developing a Reference Photon Dissemination System at 1550 nm wavelength (namely, RPDS1550) that has applications in gravitational wave detectors. Presented below is a brief summary some of the related instrumentation work that they have carried out in last one year.

Present team members - Sumit Ghosh (UG student), Venu Jangam (UG student), Samarth Kulkarni (UG student), Sankalpa Banerjee (doctoral student), Stanley Johnson (research associate), Sankar Majhi (scientific officer) and Subhadeep De (project investigator).

A coherent optical fiber system (namely the "PhotonSync^{TM}" for dissemination of optical clock signals to remote locations

Optical fibers suffer from random changes in their length, primarily due to temperature fluctuations, acoustic noise, and vibration picked up from the environment, resulting in phase change and Doppler shifts in the photons transmitted through them. The intercomparison of remote optical clocks, which depends on unperturbed transmission of optical frequencies, thus requires real-time measurement and compensation of the random phase. IUCAA scientists have developed a complete digital hardware "PhotonSync^{TM}" (Fig. 13), to measure and compensate for the phase and frequency fluctuations encountered by light transmitted over the optical fiber. They have experimentally demonstrated the performance of this system, using fiber spools of up to 71 km and a 4 km deployed fiber link within the IUCAA campus. In addition to fiber phase stabilization, the system constantly measures and corrects slow frequency drifts ($30-100$ mHz/sec) of the source's ultra-stable narrow linewidth laser. Figure 14 shows Allan deviation of a 71 km long, phase-stabilized fiber and compares that to an unstabilized situation. An optical-difference frequency comb, locked to a Rubidium clock, was used as an absolute optical frequency reference in order to measure the drift of the ultra-stable laser. This is depicted in Fig. 2 (b) for three different scenarios, when drift compensation was inactive, and when it was activate using optical self referencing, and absolute optical referencing techniques. The active drift correction suppresses the drift to 7.49 mHz/s, compared to the uncorrected 32.36 mHz/s.

High-performance low-noise active temperature controller

Development of a narrow linewidth ultra-stable laser, for the optical clock development, requires frequency locking of a laser to reference Fabry-Perot (FP) cavity having a fractional length stability of $\sim 10^{-16}$, which in turn requires maintaining its zero crossing temperature within few mK accuracy. We developed a high-performance and low-noise active temperature controller to meet the desired needs. A Wheatstone bridge is used to detect the resistance variation of a 10 MΩ thermistor that is used as a temperature sensor with an adjustable resistor for first-time calibration. The temperature sensor is based on a 32-bit precision multi-channel Analogue to Digital Converter (ADC) with an inbuilt Digital Signal Processing (DSP) for noise filtering. It has a programmable gain Operational Amplifier (OPAMP) with 10 MΩ input impedance, which has programmable integration time allowing an enhanced analogue resolution that can be adjusted by trading off the sampling rate. We are using a 32-bit ARM microcontroller for interfacing with the ADC to implement a Proportional-Integral-Derivative (PID) and also for sending a 16-bit Pulse Width Modulation (PWM) control signal to an H-bridge to drive the Thermo-Electric Coolers (TECs) attached to the vacuum chamber housing the FP-cavity. A microcontroller is connected to a computer using the programmer/debugger connector for firmware upgrading and debugging, as well as a USB cable for communicating with the temperature controller to prefix the temperature set point, PID values, and retrieving the temperature data for logging and monitoring purposes. To detect the temperature drift of the board and noises, we add a dummy Wheatstone bridge with exactly the same batches of calibrated resistance; this will provide us with the noise and drift of the temperature detection circuit. We have two PT100 Surface Mount Device (SMD) temperature sensors to compensate for any drift in data, which needs to be calibrated for each thermistor module. The board will be capable of handling six 32-bit external thermistor temperature sensors and 10 outputs for the H-bridge driver with PWM control. Forty-hour recorded drift in temperature and its noise are shown in Fig. 15, respectively, which shows a drift of ∼500 μK. Upon calibrating the thermistor temperature sensors compensating for the PCB temperature, slow drift (<1 mHz) due to environmental factors can be eliminated. The dotted line shows the resolution limit of the system, but that will not affect the performance of the system, as any high frequency (>1 mHz) fluctuation will be averaged out by the thermal shields.

A low-noise current controller for driving an extended cavity diode laser

A precision current controller is crucial for driving of an extended cavity diode laser (ECDL) for its high stability, high accuracy, and low noise operation. We developed such a current controller that comprises

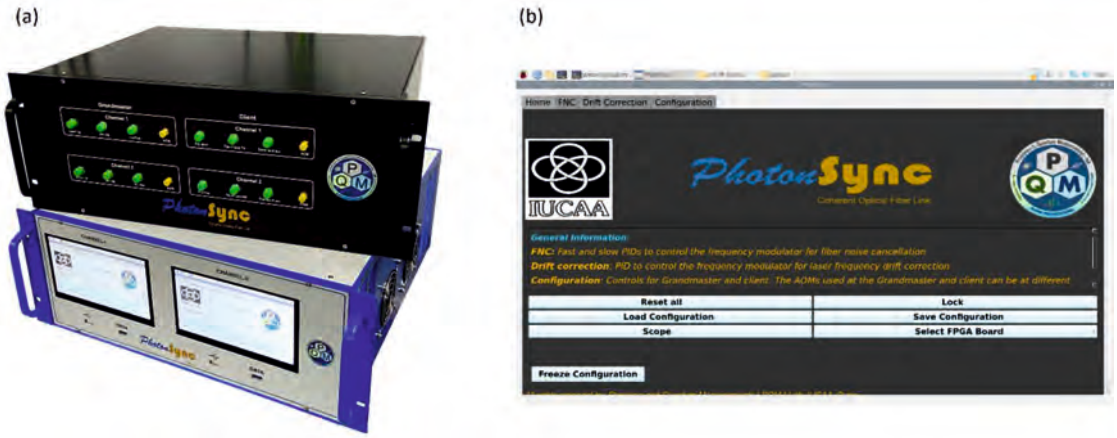


Figure 13: (a) The PhotonSync servo controller (bottom) and the optics enclosure (top). (b) The main page of the graphical user interface for the PhotonSync system.

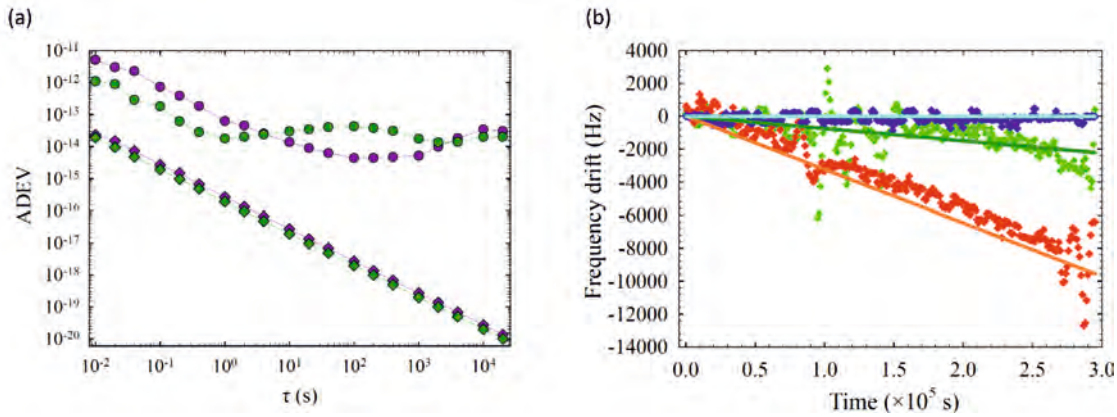


Figure 14: (a) Allan deviation (ADEV) of the fractional frequency instability for the in-loop beat signal for a fiber spool of length 71 km (dark purple) and for a 3.3 km deployed fiber link (dark green). Circles and diamonds depict the ADEV when the phase noise compensation is inactive and active, respectively. (b) Frequency drift of the ultra-stable laser, with drift compensation active (self-referencing: green symbols, absolute optical frequency referencing: blue symbols) and inactive (red symbols). The lines depict the linear fit for drift compensation active (self-referencing: dark green, absolute optical frequency referencing: cyan) and inactive (orange) cases.

(i) Libbrecht-Hall module, (ii) current modulation, (iii) monitoring, (iv) photo-diode-based optical output power readout, (v) slow turn on/off, and (vi) low-noise power supply. The heart of the circuit is the Libbrecht-Hall section, based on an opamp-mosfet feedback arrangement with a precision sampling resistor connected to the drain of a p-channel MOSFET. The current modulation section is useful for external modulation and feedback control. The current monitoring helps monitor the actual current applied to the laser diode. The photo-diode readout section measures the optical output power of the laser diode using the electrical signal from the inbuilt photo-diode within the laser diode. In case of any transient response, the slow turn-on/off section protects the laser diode from any damage. There are different supply sections for control electronics and the laser diode, which are helpful in controllability and minimizing the noise coupling to the laser diode. We have designed a p-channel MOSFET-based positive current source as well as an n-channel MOSFET-based negative current source. The p-channel MOSFET-based current controller was finally chosen due to its gate drive simplicity and easier integration. The measured noise

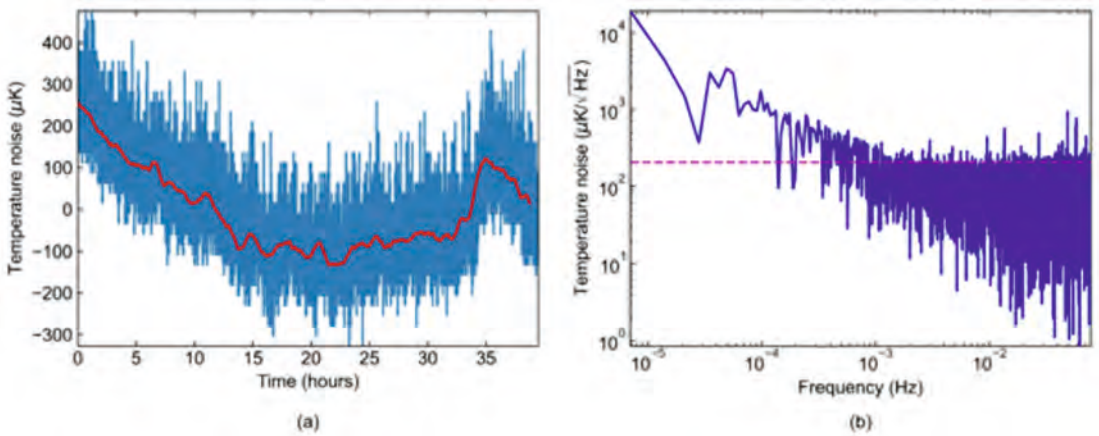


Figure 15: The temperature noise of the sensor (a) The noise is shown in cyan, and the red indicates the average drift in the reading due to a change in lab (PCB) temperature. (b) The Amplitude Spectrum Density (ASD) of the temperature noise is shown in blue, and the dotted line shown in magenta shows the temperature sensor's noise floor.

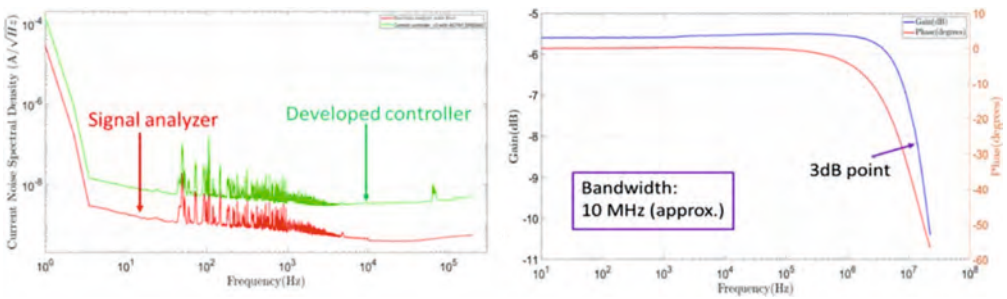


Figure 16: (a) Noise floor of the current controller, and (b) amplitude and phase response of modulation input.

Figure 17: Complete extended cavity diode laser (ECDL) controller.

floor (Fig. 4a) of the controller is around 3×10^{-9} $A/\sqrt{Hz}$ at 1 kHz. The amplitude and phase response of the modulation input of the controller is shown in Fig. 16, and the 3 dB modulation bandwidth is ~10 MHz. We measured its stability of < 2 μA over a period of 3 days for a set current of 250 mA. We have developed and packaged a complete laser controller that comprises a piezo controller (reported in the previous year's annual report), current controller, and temperature controller, which can be controlled using a Python-based graphical user interface (GUI), as shown in Fig. 17.

Solar and Stellar Physics

Evolution of the Ratio of Mg II during Solar Flares

The Mg II k and h line intensity ratios can be used to probe the characteristics of the plasma in the solar atmosphere. It has been established that the intensity ratio of the k to h line is 2:1 in the optically thin conditions and is lower when the medium is optically thick. Therefore, the intensities of lines could be used to probe the nature of the local plasma during flaring. Here, **Soumya Roy & Durgesh Tripathi** studied the evolution of the Mg II h and k line inten-

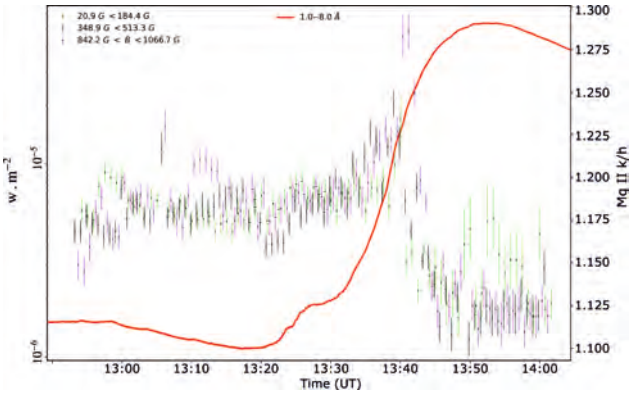


Figure 18: Mg II k-to-h-line intensity ratio as function of time for M-class flare observed on 2015 November 4, for different magnetic field bin. Over-plotted red solid line displays the 1–8 Å GOES X-ray light curve.

sity ratios in the course of the evolution of three flares corresponding to difference classes, viz., C-class, M-Class, and X-class. The focus was also given on the dependence of line ratios on the underlying magnetic field strength. It was found that the changes in the ratios is highest during the impulsive phase of the flare (see Fig. 18) and starts to decrease before the flare reaches its maximum in soft X-rays as measured in (Geostationary Operational Environmental Satellites) GOES. Such changes may indicate variation in the opacity of the local medium. In this scenario, the optical depth first decreases during the impulsive heating phase and starts to increase during the decay phase. While the decrease in the optical depth during the impulsive phase may be attributed to localized heating and chromospheric evaporation, the increase during the decay phase of the flare may be explained by condensation and down flows.

Thermodynamic Evolution of Plumes

In this study, **Biswanath Malaker & Durgesh Tripathi** with their collaborator investigate the full life cycle of a coronal plume observed within a coronal hole (see Fig. 19) using data from the Atmospheric Imaging Assembly (AIA) and the Helioseismic and Magnetic Imager (HMI), both on board Solar Dynamics Observatory (SDO). The plume forms following frequent small-scale jets and jetlets at its base, which gradually generate plume haze. Within six hours, it develops its characteristic structure. Light curves across extreme ultraviolet channels show similar trends, indicating a multi-thermal nature with intensity changes over time. Magnetic field activity

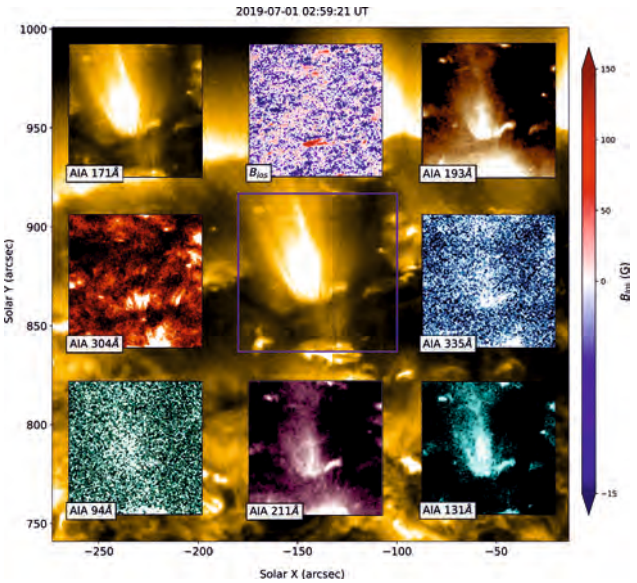


Figure 19: Solar polar plume at its peak intensity depicted in the background image. This is observed in the 171 Å band of the AIA instrument on SDO, on 2019 July 1 at 02:59:21 UT. The insets show the plume in all AIA passbands, along with the line of sight magnetic field obtained from HMI on board SDO in the top-middle inset. The color bar sets the scale for the line-of-sight magnetic field.

at the base strongly correlates with 171 Å emissions. Outflows, which are most evident in the 171 Å passband, show varying speeds, generally slower at higher temperatures. While the plume appears isothermal on large scales, high-resolution differential emission measure analysis reveals internal temperature variations. These findings offer new insights into plume dynamics and thermal structure, enhancing our understanding of their role in solar wind formation.

Science filter characterization of the Solar Ultraviolet Imaging Telescope (SUIT) on board Aditya-L1

In this study, **Janmejoy Sarkar, A.N. Ramaprakash and Durgesh Tripathi** with collaborators from IUCAA, ISRO and several other institutions perform the complete characterization of the science filters on the SUIT instrument of Aditya-L1. The SUIT telescope uses 16 dichroic filters at specific wavelengths to meet its science objectives. To ensure accurate data, the filters were characterized for spectral variations across spatial locations and tilt angles using the test setup in

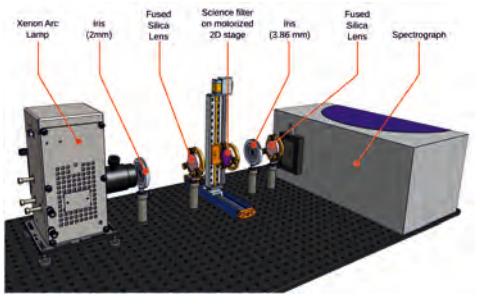


Figure 20: SUIT Science Filter characterization setup.

Fig. 20. In-band and out-of-band transmission properties were also measured. Results show that all filters meet expected performance. These findings confirm SUIT's ability to effectively observe key solar atmospheric features.

Near- and Mid-ultraviolet Observations of X-6.3 Flare on 2024 February 22 Recorded by the Solar Ultraviolet Imaging Telescope on board Aditya-L1

This is the first reported solar flare observation from the Solar Ultraviolet Imaging Telescope onboard Aditya-L1 by **Soumya Roy & Durgesh Tripathi**, with collaborators from IUCAA and several other organizations. On February 22nd, three solar flares occurred from a sunspot group. The first flare was not observed by SUIT as it was pointed away to Sirius for verifying the photometric calibration sequences. The third flare, however, is presented in this work. This is the first observation of a solar flare in some of the wavelengths e.g. NB6 (300 nm), NB7 (388 nm), NB2 (276.7 nm) and NB1(214 nm) as seen in Fig. 21. The authors also reported the first results from the SoLEXS soft X-ray spectrometer. It is seen that the soft X-ray temperature peaks at the same time as Mg II k and h lines and Ca II h lines, along with observations from H-alpha. We also see a delay in the flare peak in the red and blue wings of Mg.

The Solar Ultraviolet Imaging Telescope on Board Aditya-L1

Durgesh Tripathi, A.N. Ramaprakash, and collaborators from IUCAA and other institutions report on the Solar Ultraviolet Imaging Telescope (SUIT), a key payload onboard ISRO's Aditya-L1 mission launched in September 2023 (Fig. 22). SUIT captures full-disk images of the Sun across 11 filters within

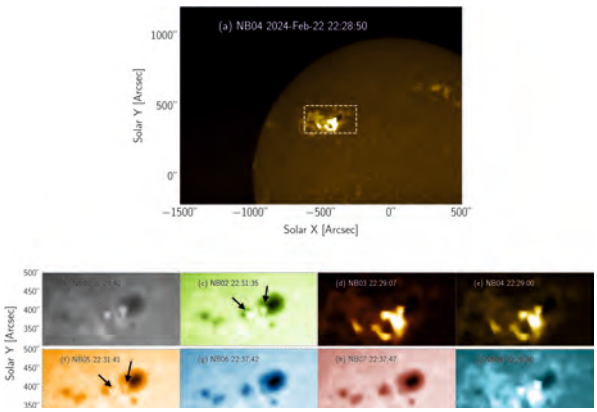


Figure 21: X-6.3 Solar Flare on 2024 February 22 observed by the SUIT.

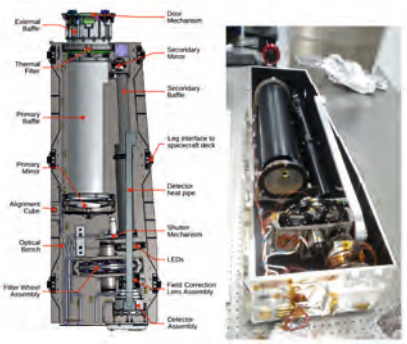


Figure 22: Schematic diagram and photograph of the SUIT instrument of Aditya-L1

the 200–400 nm wavelength band. This enables detailed observations of the solar photosphere and chromosphere. These measurements will enhance the understanding of solar atmospheric coupling and, for the first time, provide spatially resolved NUV data of the Sun. This data is critical for modeling the variability of solar UV irradiance, vital for studying Earth's stratospheric chemistry. The paper outlines SUIT's instrumentation and initial data products.

EMISSA (Exploring millimetre indicators of solar-stellar activity). III. Comparison of Ca II indices and millimetre continua in a 3D model atmosphere

Led by **Sneha Pandit**, the overall aim of this work is to establish more robust solar/stellar activity indicators using ALMA observations in comparison with classical diagnostics, such as the s index and infrared triplet (IRT) index. She synthesized Ca II and

mm data from a close-to-realistic high-resolution solar model. The work mostly uses statistical methods to compare the classical and millimetre indicators. This can further be used to precise the imaging techniques in mm interferometric data.

Discovery of RR Lyrae in Ultra-faint Dwarf Galaxies

Discovery and characterization of RR Lyrae variable stars in the ultra-faint dwarf galaxies (UFDs) is useful for probing their metallicities and distances. In collaboration with Chow-Choong Ngeow from National Central University, Taiwan, IUCAA faculty **Anupam Bhardwaj** discovered three RR Lyrae variables in a newly identified Virgo III UFD galaxy and determined its distance (Ngeow and Bhardwaj 2024). Similarly, the authors carried out RR Lyrae searches in Aquarius III and Sextans II UFD galaxies using both archival data from time-domain surveys and dedicated follow-up observations. While a candidate RR Lyrae variable was found in Aquarius III, there were no RR Lyrae stars in Sextans II. The lack of RR Lyrae stars in Sextans II was consistent with other previously-known fainter UFDs with similar visual magnitude that do not have these variable stars. These studies also revisited the relation between absolute visual magnitude and the number of RR Lyrae found in local galaxies (Figure 23), demonstrating that this empirical relation is better described with the specific RR Lyrae frequency.

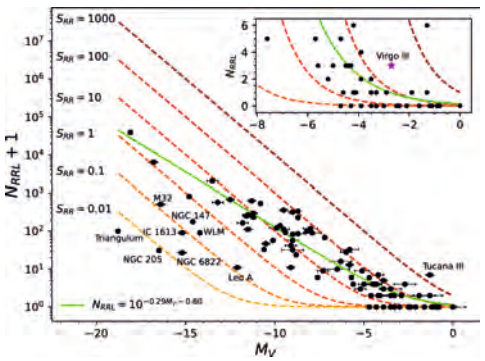


Figure 23: Number of RR Lyrae ($N_{\rm RRL}$) as a function of visual absolute magnitude (M_V) for the 94 galaxies adapted from Ngeow & Bhardwaj (2024). The green solid curve represents the empirical relation derived in Martńez-Vázquez et al. (2019). The dashed curves are for the different selected values of specific RR Lyrae frequency SRR. The inset figure is the zoomed-in version for UFD galaxies with $N_{\rm RRL} < 7$, where Virgo III is marked as a magenta star.

New theoretical framework on BL Herculis stars

Classical pulsators obey Period-Luminosity (PL) relations, which are vital tools for extragalactic distance measurements. Different galaxies have different metallicities, resulting in a non-universal PL relation of classical pulsators. A precise calibration of metallicity contribution remains one of the most important challenges. In collaboration with international researchers, IUCAA postdoc **Susmita Das**, together with IUCAA faculty **Anupam Bhardwaj**, developed a new theoretical framework on BL Herculis stars and obtained a precise calibration of metallicity contribution towards PL relations. BL Herculis stars are a specific class of classical pulsators that have been studied far less than other classical pulsators but offer a huge advantage with their negligible metallicity effects on PL relations, thereby making them ideal candidates for obtaining a truly universal PL relation to measure distances in the Universe.

Important results include providing a new theoretical PL relation in the upcoming Rubin Observatory LSST survey pass bands obtained from a fine grid of BL Her models using MESA-RSP. In another study, a robust light-curve fitting algorithm was developed to compare theoretical and observed light curves of BL Her stars, providing stellar parameter estimations for stellar mass, stellar luminosity, chemical composition and effective temperature of BL Her stars in the LMC (shown in Fig. 24).

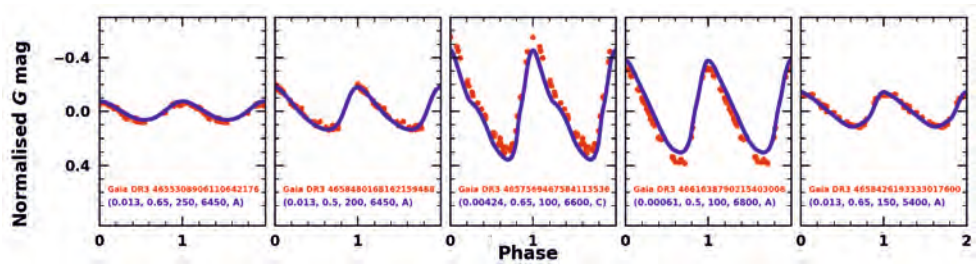


Figure 24: An excerpt of light curves (normalized with respect to their mean magnitudes) of BL Her stars in the LMC (in red) with their best-matched models (in blue) in the Gaia G passband. The input stellar parameters of the corresponding models are included in the format ($Z, M/M_{\odot}, L/L_{\odot}, T_{\rm eff}$, convection set) in each subplot.

PEDAGOGICAL

(a) IUCAA-NCRA GRADUATE SCHOOL LECTURES

Ranjeev Misra:

Electrodynamics and Radiative Processes I (August 05 - October 04, 2024)

Debarati Chatterjee:

Quantum and Statistical Mechanics I (August 05 - October 04, 2024)

Aseem Paranjape:

Methods of Mathematical Physics II (October 14 - December 13, 2024)

Durgesh Tripathi:

Introduction to Astronomy and Astrophysics II (October 14 - December 13, 2024)

Dipanjan Mukherjee:

Electrodynamics and Radiative Processes II (October 14 - December 13, 2024)

Aseem Paranjape:

Quantum and Statistical Mechanics II (October 14 - December 13, 2024)

Rajeshwari Dutta:

Interstellar Medium (March - May 2024)

Subhadeep De:

Research Methods and Statistical Techniques (January 06 - March 07, 2025)

Surhud More:

Extragalactic Astronomy I (January 06 - March 07, 2025)

Kanak Saha:

Galaxies: Structure, Dynamics and Evolution (January 06 - March 07, 2025)

A.N. Ramaprakash:

Astronomical Techniques - I (January 07 - March 07, 2025)

R. Srianand:

Interstellar Medium (March 17 - May 16, 2025)

(b) SPPU-IUCAA JOINT M.Sc. (PHYSICS WITH ASTROPHYSICS) PROGRAMME and The DEPARTMENT OF PHYSICS, SPACE SCIENCES, SPPU, M.Sc. (ASTRO) Lectures

Sanjit Mitra:

Relativistic Electrodynamics and Radiation Processes (July - December 2024)

Anupam Bhardwaj:

Introduction to Astronomy and Astrophysics I and II (July - December 2024)

Rajeshwari Dutta/Vaidehi Paliya:

Astronomical Techniques (July - December 2024)

Rajeshwari Dutta:

Astrophysics Laboratory I (July - December 2024)

Gulab Chand Dewangan:

High-Energy Astrophysics (April - May 2024)

Dipanjan Mukherjee:

Astrophysical Dynamics (January - May 2024)

Shasvath Kapadia:

General Relativity and Cosmology (January – May 2024) & (January – May 2025)

Nishant Singh:

Astrophysical Dynamics (January – May 2025)

Vaidehi Paliya:

High-Energy Astrophysics (January – May 2025)

Sowgat Muzahid:

Astrophysics Laboratory II (January – May 2025)

(c) Department of Physics, Cooch Behar Panchanan Barma University, Cooch Behar - I-CARD. Teaching: M.Sc. students

Kanak Saha:

Course-Group D, Astrophysics and Cosmology - May 19 to June 06, 2024 (Twelve days of classes, two-hour lecture every day).

(d) SUPERVISION OF Ph. D. THESES (IUCAA)

(Degrees Awarded)

Debarati Chatterjee

Title: *Constraining Neutron Star Equation of State using Multi-disciplinary Physics and its application in studying various aspects in Gravitational Wave emission.*

Student: Suprovo Ghosh

Title: *"Study of the effect of Neutron Star composition on fluid oscillation modes and Gravitational Wave emission.*

Student: Bikram Keshari Pradhan

Gulab Chand Dewangan

Title: *AstroSat view of accretion discs in Active Galactic Nuclei.*

Student: Shrabani Kumar

Neeraj Gupta

Title: *An unbiased view of cold atomic gas associated with radio loud AGNs.*

Student: Partha Pratim Deka

Sanjit Mitra

Title: *Efficient Searches for Compact Binary Coalescences and Science in the LIGO-India Era.*

Student: Kanchan Soni

Surhud More

Title: *Gravitational lensing in Galaxy clusters*

Student: Amit Kumar

Title: *Gravitational lensing: Galaxy dark matter connection and cosmology*

Student: Navin Lalta Prasad Chaurasiya (co-supervised with Anupreeta More)

Title: *Measuring Cosmological Parameters with Gravitational-Wave Observations*

Student: Tathagata Ghosh

Dipanjan Mukherjee

Title: *Modelling the impact of AGN-driven outflows on the star formation activity in galaxies.*

Student: Ankush Mandal

Title: *Simulating effects of AGN-driven outflows on galactic scales and predicting their observable signatures.*

Student: Meenakshi

Aseem Paranjape

Title: *Exploring the nature of dark matter using astrophysical and cosmological probes.*

Student: Bhaskar Arya

Title: *Interplay of galaxy formation and the evolution of dark matter haloes in the cosmic web.*

Student: Premvijay V

(e) SUPERVISION OF Ph. D. THESES (IUCAA)

(Ongoing)

Anupam Bhardwaj

Title: *Peculiar Horizontal Branch Morphology and RR Lyrae variability in star clusters.*

Student: Prashant Nishad

Debarati Chatterjee

Title: *Consistent finite temperature models of Neutron Stars for studies of Gravitational Wave emission.*

Student: Nilaksha Barman

Title: *The Implications of Fundamental Physics on Neutron Star Properties and associated Gravitational Wave Emission.*

Student: Rajesh Maiti

Title: *Probing exotic matter in Neutron Stars using Multi-Messenger Astronomy.*

Student: Swarnim Shirke

Title: *Role of Bulk Viscosity in Gravitational Wave Emission from Neutron Stars.*

Student: Pranjal Tambe

Gulab C. Dewangan

Title: *Accretion disk-corona interplay in Active Galactic Nuclei*

Student: Kavita Kumari (Thesis submitted).

Title: *Active Galactic Nuclei and bright UV sources in the AstroSat/UVIT fields.*

Student: Piyali Ganguli

Title: Tidal effects in compact objects.

Student: Rajendra Prasad Bhatt (Co-supervised with Sukanta Bose)

Neeraj Gupta

Title: *An unbiased view of cold atomic gas associated with radio loud AGNs.*

Student: Partha P. Deka

Shasvath Kapadia

Title: *Prospects for probing dense stellar environments with gravitational waves emanated by accelerated compact binary coalescences.*

Student: Avinash Tiwari

Title: *Observing lensed and unlensed gravitational waves with current and future-generation detectors.*

Student: Sourabh Magare

Title: *Astrophysical Inference Using Continuous Gravitational Waves and Gravitational Lensing Of Gravitational Waves.*

Student: Gopalkrishna Prabhu

Title: *Searches for Lensed Gravitational Waves and Overlapping Gravitational Wave Signals.*

Student: Sudhir Gholap

Supervisor of Sajad Bhat, post-doctoral fellow

Sanjit Mitra

Title: *Searches and astrophysical implications of gravitationally lensed gravitational waves.*

Student: Anirban Kopty

Surhud More

Title: *Gravitational Lensing Probes of Dark Matter*

Student: Priyanka Parshuram Gawade (co-supervised with Anupreeta More)

Student: Shreya Mukherjee

Student: Sourav Das

Dipanjan Mukherjee

Title: *Simulations of various aspects of extra-galactic relativistic jets.*

Student: Prathamesh Ratnaparkhi

Title: *Modelling magnetic fields of Accreting Neutron Stars.*

Student: Saurabh Yeole

Title: *Modelling Time-Dependent Accretion and Outflow for supermassive black holes*

Student: Raghav Gogia

Title: *Modelling the role of stellar and AGN feedback processes in galaxy evolution*

Student: Biplab Sarkar

Sowgat Muzahid

Title: *Gaseous atmospheres of high redshift Lyman-alpha emitters.*

Student: Eshita Banerjee

Title: *Probing the circumgalactic medium of low redshift galaxies*

Student: Sayak Dutta

Aseem Paranjape

Title: *Cosmic velocity flows: from theory to observations.*

Student: Saee Dhawalikar

Kanak Saha

Title: *Dark matter in Low-mass Compact galaxies.*

Student: Jyoti Prakash

Title: *Probing the ionizing radiation of high-redshift galaxies using AstroSat.*

Student: Soumil Maulick

Title: *Probing the assembly of galaxies in high-z universe.*

Student: Manish Kataria

Title: *Clump dynamics of Star-forming galaxies at intermediate redshift.*

Student: Pushpak Pandey

R. Srianand

Title: *Physics of galaxy formation and evolution at the cosmic dawn.*

Student: Ranit Kumar Behera

Durgesh Tripathi

Title: *Solar Flares across the spectrum: Observations and Instrumentation.*

Student: Soumya Roy

Title: *Multi-wavelength Observations of Polar Plumes and Jets*

Student: Biswanath Malaker

(f) SUPERVISION OF Ph. D. THESES (Other than IUCAA)

Subhadeep De

Title: *Time Transfer Over Optical Fibre Links: Impediments and Analysis.*

Student: N. Yadav (CSIR-NPL, Delhi) (Graduated in 2024).

Title: *Instrumentation and Automation for the Development of an Optical Clock.*

Student: H. Rathore (CSIR-NPL, Delhi) (Graduated in 2024).

Gulab Dewangan

Student: Pravin Patole (Ph. D. student at SRTM University Nanded),(ongoing).

Student: Shammi Kamal (Ph. D. student at Jamia Millia University, New Delhi, (ongoing).

Neeraj Gupta

Title: *HI analysis of resolved galaxies in the MeerKAT Absorption Line Survey*

Student: Eric Maina, SARAO, South Africa (degree awarded in 2024).

Title: *Testing cosmic dipole with deep radio continuum surveys.*

Student: Jonah Wagenveld - MPIfR, Germany (mentor),(degree awarded in 2024)

Vaidehi Paliya (Co-supervisor)

Title: *Energy-Dependent Flux Variations of Bright Fermi Blazars: Clues to the Radiative Processes.*

Student: Naseef Mohammed (faculty at Farook College, Calicut and registered at the University of Calicut for a PhD) (ongoing).

Durgesh Tripathi

Title: *Study of the Solar Atmosphere: Space Instrumentation and Observation.*

Student: Janmejoy Sarkar

(g) SUPERVISION OF MASTERS THESIS

Sanjeev Dhurandhar

- Harshit Raj (IISER, Pune, Masters Thesis) *A nonlinear data processing technique of searching for periodic sources of gravitational waves*

Neeraj Gupta

- Shashank Soni (M.Sc thesis, IISER, Pune) *Properties of gas in and around galaxies at z<0.6 in MALS.* (M.Sc. awarded in 2024).

Kanak Saha

- Mayank Sekhar Singh (MS final year thesis, April 2025, IISER, Pune) *Reconstructing AstroSat UV Deep Field images using Lucy's algorithm.*

(h) SUPERVISION OF PROJECTS

Anupam Bhardwaj

- Mr. Soumik Sarkar (M.Sc. project, IUCAA-SPPU) - *The distances and metallicities of nearby dwarf galaxies.*
- Ms. Kruti Tarte (M.Sc. project, IUCAA-SPPU) - *Modeling Cepheid evolution and pulsation.*
- Mr. Sanmesh Deshmukh (VSP project) – *Probing peculiarity of RR Lyrae variable stars in the metal-rich globular clusters.*
- Ms. Tanishka Agiwal (VSP project) – *Mapping the Distance Scale to Nearby Dwarf Spheroidal Galaxies.*
- Ms. Dnyanada Kulkarni (BSc. thesis, Fergusson College) – *Time-series photometry of RR Lyrae in globular clusters.*

Debarati Chatterjee

- Yatharth Chaurasiya (SPPU-IUCAA M.Sc. Physics with Astrophysics, September 2023 – May 2024), *Gravitational Waves as a Probe of Quark Matter in Compact Stars.*
- Puja Mandal (SPPU-IUCAA M.Sc. Physics with Astrophysics, September 2024 – May 2025), *Implications of the non-detection of continuous gravitational waves on the Neutron star interior.*

Subhadeep De

- M Gautham Upadhyaya (IISER, Pune) 2024, *Designing and Vibration Analysis of a Transportable Reference Optical Cavity.*

Sanjeev Dhurandhar

- Gautam Singh and Dalika Joshi (Fergusson College, Pune, B.Sc. project) *Special and General Relativity and its Applications.*

Rajeshwari Dutta

- Gitanjali Erassery Rajulal, (VSP Project), June-July 2024, *Metal-enriched gas around galaxies.*

- Mehak Gupta, SPPU-IUCAA M.Sc. Semester III & IV project., July 2024 - May 2025, *Metal-enriched gas around galaxies.*

Neeraj Gupta

- Trishala Majumdar [SPPU-IUCAA M.Sc. 2022-2024 batch] *Properties of young radio loud AGN in MALS.*
- Soubhik Pramanik [SPPU-IUCAA M.Sc. 2022-2024 batch] *Multiwavelength properties of galaxies in MALS.*

Sanjit Mitra

- Haraprasad Nandi [IISER, Pune, M.S. Project, July - December 2024] *Machine Learning Techniques for Fabry-Perot Cavity Alignment*
- Antara Ghosh [BITS Pilani, Hyderabad campus, first degree thesis, January - June 2025] *Assessing the Improvement in Gravitational Wave Detection by Daksha and LIGO India Jointly Operating with the Existing Network of Detectors.*

Surhud More

- Prajakta Mane [IISER, Mohali] *Strategies to identify strongly lensed type Ia supernovae in Rubin LSST* [co-supervised with Anupreeta More]
- Devesh Yadav [SPPU-IUCAA M.Sc.] *Determining the Hubble constant from Gravitational wave data.*

Sowgat Muzahid

- Ayush Kachhwaha [SPPU-IUCAA M.Sc.] *Galaxy survey using 3D spectroscopic data.*

Vaidehi Paliya

- Ayushi Kotecha [SPPU-IUCAA M.Sc.] *Characterizing the Gamma-ray Flaring Behavior of Bright Fermi Blazars.*
- Jowhara Jafar [University of Calicut, Calicut, M.Sc. Physics] *On the Multi-wavelength Behavior of the Blazar Candidate 4FGL J0622.9+3326.*
- Roshani Naik, Sanket Thakur, Avantika Sangole, and Swati Dhabekar [Fergusson College, Pune, M.Sc. Physics] *Giant Radio Sources as seen by Low Frequency Array.*

Aseem Paranjape

- Aryan Singh [SPPU-IUCAA M.Sc. 2023-24 batch] ***Cosmological N-body simulations.***
- Soumyadeep Mandal [SPPU-IUCAA M.Sc. 2024-25 batch]
- Gaurav Pundir [IISER, Pune, One-year MS thesis 2024-25]
- Satyapriya Das [IIST, Kerala, VSP student, January - August 2024]

Kanak Saha

- Koshal Saini [SPPU-IUCAA M.Sc. 2024-25] *Numerical exploration of orbits of a circumbinary planet.*

(i) SEMINAR/COLLOQUIA/LECTURES/POSTERS

Anupam Bhardwaj

Cosmic Distance Ladder and the Hubble tension, [Invited talk], Tensions and Anomalies on the Sky, CTP JMI, India, Mar 2025.

Stellar route to the Hubble constant, [Invited talk], 43rd Meeting of the Astronomical Society of India, NIT Rourkela, India, Feb 2025.

Stellar Variability in the NIR in Nearby Galaxies, [Invited talk], The Milky Way and Andromeda – Odd Couple Conference, Sexten, Italy, Feb 2025.

Cosmic Distance Ladder and the Hubble constant, [Invited talk], 33rd Indian Association for General Relativity and Gravitation, BITS Pilani, Rajasthan, Jan 2025.

Automated Classification of Pulsating Variable Stars and their Fundamental Parameters with ML, [Invited talk], AI/ML Applications in Astronomy & Astrophysics Conference, IUCAA, India, Jan 2025.

Stellar route to the Hubble constant, [Invited talk], Testing Gravity with Multi-messenger Astronomy, IIT Bombay, India, July 2024.

Exploiting Precision Distance Indicators in the Gaia Data, EXPANDING Universe Team Meeting, ISSI Beijing, China, Jan 2025.

Dwarf Galaxies in the NIR and their RR Lyrae and Anomalous Cepheids, CepRRL 2024 conference, Morocco, Nov 2024.

Two lectures on *Stellar Structure, Evolution, and Pulsation*, Workshop on Stellar Evolution and Pulsation modelling, DDU Gorakhpur, March 2025.

Two lectures on *Fundamentals of Astronomy and Stellar Structure and Evolution*, Introductory Workshop in Astronomy and Astrophysics, Dehradun, December 2024.

Two lectures on *Stellar Structure, Evolution, and Pulsation*, Introductory Workshop in Astronomy and Astrophysics, Kerala, November 2024.

Pulsating stars and the Hubble constant, Workshop on Stars and Galaxies, Guwahati, September 2024.

Stellar Pulsations [Special Lecture] IUCAA-NCRA Graduate School.

Stellar Structure and Evolution, 17th Radio Astronomy Winter School, December 14-24, 2024.

Swadesh Chand

AstroSat View of the Accretion Geometry of GX 339-4 in the Hard State, oral presentation, Recent Trends in the Study of Compact Objects: Theory and Observation (RETCO-VI), Indian Institute of Technology, Indore, MP, India, March 10 - 12, 2025.

Debarati Chatterjee

Gravitational waves from Neutron stars as Probes of Fundamental Physics, Physics Seminar, Institute of Mathematical Sciences (IMSc), Chennai, Nov 5, 2024.

Group seminar at the Institut für Theoretische Astrophysik (ITA), Heidelberg, May 27, 2024.

What Gravitational Waves can tell us about Fundamental Physics, Invited SOTU (State of the Universe) seminar, Tata Institute of Fundamental Research, Mumbai, April 17, 2024.

Unravelling the interior of Neutron Stars with Gravitational Waves, IUCAA Colloquium, February 27, 2025.

Neutron stars as probes of Fundamental Physics in light of multi-messenger astronomy, Colloquium, Department of Physics, Ashoka University, Sonepat, April 4, 2024.

Kalpesh Chillal

Challenges in Upgradation and Testing of IFOSC CCD Controller, oral presentation, 43rd Astronomical Society of India meeting (ASI 2025), Rourkela, Odisha.

Sourav Das

Statistical signature of bioconical outflows traced by HI and OVI, talk at the Baryons Beyond Galactic Boundaries (BBGB) 2024 conference, December 02 - 06, 2024, IUCAA, Pune.

Testing the Etherington relation with SN and BAO, talk presented at the 33rd Indian Association for General Relativity and Gravitation (IAGRG) 2025 conference, BITS, Pilani, Rajasthan, January 02 - 04, 2025.

Testing the Etherington relation with SN and BAO, talk presented at the fourth chapter of the Pune-Mumbai Cosmology and Astro-Particle (PMCAP) meeting, IIT, Bombay, February 07 - 08, 2025.

Etherington distance-duality relation using SN and BAO, poster presented at the 43rd Astronomical Society of India (ASI) meeting, National Institute of Technology, Rourkela, Odisha, February 15 - 19, 2025.

Susmita Das

An updated theoretical scenario of BL Herculis stars, 43rd Meeting of the Astronomical Society of India, NIT Rourkela, India, February 2025.

Classical pulsators as Distance Indicators from the theoretical perspective, EXPANDING Universe Team Meeting, ISSI Beijing, China, January 2025.

One lecture on *Stellar Variability* and *two hands-on sessions on using the radial stellar pulsation code, MESA-RSP*, Workshop on Stellar Evolution and Pulsation modelling, DDU Gorakhpur, March 2025.

An introduction to Variable Stars and one hands-on session on using Gaia archival data, Introductory Workshop in Astronomy and Astrophysics, Dehradun, December 2024.

Subhadeep De

Optical Atomic Clock: A Sensor with Unprecedented Accuracy, IIT Indore, 25 March 2025.

Instrumentation for Sensing With Unprecedented Accuracy, IUCAA, 20 February 2025.

Instrumentation Associated with Building a Ytterbium-ion Optical Atomic Clock, Physics with Trapped Charged Particles, 13-14 November 2024.

Development of a Ytterbium-ion Optical Clock to Explore Fundamental Science, URSI-RCRS 2024, 22-25 October 2024.

Quantum Clock for Quantum Metrology, Advances in Astronomy: Integrating Technology in Astronomy Research, VIIT and IUCAA, 01-05 April 2024.

Gulab C. Dewangan

Multi-wavelength Insights into Accreting Black Holes with AstroSat, Colloquium at NCRA Pune, 9 July 2024.

Multi-wavelength Probes of Accreting Black Holes with AstroSat, E1.7 COSPAR Assembly, Busan, South Korea, 14 July 2024.

UV/X-ray probes of accretion disk/corona in radio-quiet AGN with AstroSat, E1.9 COSPAR Assembly, Busan, South Korea, 20 July 2024.

UV/X-ray investigations of radio-quiet AGN with AstroSat, [Invited talk] at the 5th Indo-China Workshop, 20 December 2024.

X-ray View of Active Galactic Nuclei, High Energy Astrophysics Workshop, Banaras Hindu University, 26 November 2024.

Introduction to X-ray Astronomy (Hands-on session X-ray), High Energy Astrophysics Workshop, Banaras Hindu University, 26 November 2024.

Indian X-ray Astronomy Space Missions: AstroSat and Future, High Energy Astrophysics Workshop, Banaras Hindu University, 27 November 2024.

Accretion-Powered Galactic Nuclei: Extreme Variability and Transient Phenomena, TIFR Mumbai, Wednesday colloquium, 5 February 2025.

UV/X-ray study of AGN with AstroSat, Invited talk at VI RETCO meeting, 10 March 2025.

Sanjeev Dhurandhar

Time-delay interferometry for space detectors of gravitational waves: the underlying mathematical structure, colloquium, CENTRA, Department of Physics, Instituto Superior Técnico, University of Lisbon, Lisbon, Portugal, April 17, 2024.

Delivered two lectures on *Gravitational Waves: A Window to the Cosmos, an* Astronomical boot camp, Nehru Planetarium, Delhi, July 10, 2024.

Data Analysis of Gravitational Wave Observations, delivered the keynote address at the National Seminar on Data Innovation in Astronomy, Amity University, Kolkata, January 03, 2025.

The Unified Chi Squared [Invited talk] National Seminar on Data Innovation in Astronomy, Amity University, Kolkata, January 04, 2025.

Rajeshwari Dutta

Studying Galaxies using the Hydrogen 21-cm Line, [Invited talk] Lecture at Radio Astronomy School, Fergusson College, Pune, 24 February 2025.

Interstellar Medium, Invited Lecture at Science, Astronomy, and Society MSFDA Workshop, GH Raisoni International Skill Tech University, Pune, 21 February 2025.

Probing the invisible cloak of gas around galaxies - the Circumgalactic Medium, Invited Plenary Talk at 43rd Annual Meeting of the Astronomical Society of India (ASI), NIT, Rourkela, 16 February 2025.

The Circumgalactic Medium: A galaxy's invisible cloak of gas, [Invited talk] Lecture at Frontiers In Physics XVIII, Fergusson College, Pune, 11 February 2025.

Probing gaseous haloes around galaxies in absorption and emission, [Invited talk] at Baryons Beyond Galactic Boundaries conference, IUCAA, Pune, 4 December 2024.

The Circumgalactic Medium: A galaxy's invisible cloak of gas, [Invited talk] Online Colloquium, Cosmology and Astronomy Researchers of Indian Nationality And Sisters (CARINAS), 28 August 2024.

Spatially resolving the CGM in absorption and emission, [Invited talk] What Matter(s) Around Galaxies 2024 conference, Varenna, Italy, 17 June 2024.

Probing metal-enriched gaseous haloes around galaxies in emission, [Invited talk] IFPU Focus Week Workshop: Where the Circum Galactic Medium meets the galaxy environment, IFPU, Trieste, Italy, 13 June 2024.

Linking CGM and galaxy environment over 12 billion years [Invited talk] Extreme galaxies in their extreme environments at extremely early epochs conference, Reykjavik, Iceland, 3 May 2024.

Probing gaseous haloes around galaxies in absorption & emission using large IFU surveys [Invited talk] Advancements in AGN, Galaxy Cluster and IGM Research workshop, CUHP, Dharamshala, 30 March 2024.

Sudhir Gholap

A χ2 statistic for the identification of strongly lensed gravitational waves

from compact binary coalescences, online talk, LIGO Lensing group, December 2024.

A χ2 statistic for the identification of strongly lensed gravitational waves from compact binary coalescences, online talk, LIGO PyCBC group, January 2025.

Basics of GW Astronomy, talk delivered to the teachers during Star Fest, February 05, 2025, LIGO India EPO at Hingoli, Maharashtra.

A χ2 statistic for the identification of strongly lensed gravitational waves from compact binary coalescences, Young Astronomers' Meet (YAM), March 18-21, 2025, TIFR Mumbai.

Neeraj Gupta

*The MeerKAT Absorption Line Surve**y***, NRAO Colloquium 2024 (October), Socorro, the USA.

The MeerKAT Absorption Line Survey; MeerKAT@5 conference 2024 (March), Cape Town, South Africa

MALS: Cold gas in and around galaxies via absorption; IAU GA 2024 (August), Cape Town, South Africa

Ranjan Gupta

Recent Asteroid sample return Missions and Related Research, Infovision conference, Birla Planetarium, Hyderabad, June 09 - 12, 2024.

Artificial Neural Networks application to Astronomical Spectra, Guwahati University, Guwahati, September 4, 2024.

Dust Modeling of Proto Planetary Disk Observation, (online), EPOPEE meeting at IPAG, University of Grenoble, Grenoble, France on September 18, 2024.

Shasvath Kapadia

Rates of gravitational-wave sources and properties of their associated GRB counterparts, [Invited talk] Plenary speaker at the 43rd Annual Meeting of the Astronomical Society of India, National Institute of Technology, Rourkela, Odisha, February 15 - 19, 2025.

Gravitational-Wave Data Analysis, [Invited lecture] Second School on Black Holes and Gravitational Waves, IIT Madras, India, February 10 - 14, 2025.

Gravitational Lensing of Gravitational Waves [Invited talk] 33rd workshop on General Relativity and Gravitation in Osaka, Japan, December 02 - 06, 2024.

Probing the line-of-sight acceleration of merging compact objects with gravitational waves [Invited talk] seminar at IIT Madras, Chennai, India, 2024.

An Overview of Gravitational-Wave Astronomy and Its Ability to Probe Dense Stellar Environments [Invited talk] CosmoGravitas conference in Mahidol University, Nakhon Sawan, Thailand, June 10 - 14, 2024.

Gravitational-Wave Astronomy: Listening to Cosmic Whispers with the LIGO-Virgo-Kagra Detector Network [Invited talk] Beckman Centre in Los Angeles, California, by the United States National Academy of Sciences (NAS), 2024.

Ravi Kesharwani

*Innovation of New Technology for Space Astronomy***,** National Space Day celebration, Motilal Nehru Advanced Institute of Technology (MNNIT), Allahabad, August 23, 2024.

Engineering in Space Astronomy, Dr. D.Y. Patil Institute of Engineering Management and Research, Pune, September 21, 2024.

Sanjit Mitra

LIGO-India and BNS mergers (Invited talk), Transients 2024, IIT Bombay, April 01, 2024.

How a deci-hertz detector can augment Cosmology & Tests of GR in the LIGO-India era (Invited talk), Test of General relativity with Multi-Messenger Astronomy meeting, IIT Bombay, July 24, 2024.

Basics of Gravitational Waves (Invited talk) (online), Course on `The next generation surveys for multimessenger astronomy', Institut Teknologi Bandung, Indonesia, September 03, 2024.

Gravitational Waves & LIGO-India (Invited talk) Maharashtra State Faculty Development Academy (MSFDA), Pune, September 03, 2024.

Boosting Neutron Star Science with LIGO-India and Beyond (Invited talk) (online), Neutron Star Equation of State and Gravitational Waves (NEOSGrav2024) meeting, Goa, October 03, 2024.

Science potential in the LIGO-India era and beyond (Invited talk) (online), IIA Gravity Meeting, Kodaikanal Solar Observatory, December 06, 2024.

A deci-hertz gravitational wave mission (The most natural step), Beyond LIGO-India (Invited talk), Beyond LIGO-India meeting, IISER Kolkata, December 2024.

The future of Gravitational Wave Astronomy and LIGO-India (Invited talk), International Conference on Frontiers of High Energy Physics, IIT Bhilai, February 13, 2025.

Surhud More

The galaxy-dark matter connection with HSC survey: centrals, satellites and galaxy assembly bias, APEC seminar, Kavli IPMU, Japan, September 2024.

Cosmological constraints from Year 3 data from the Subaru Hyper Suprime Cam Survey, IIA Colloquium, September 2024.

Cosmological constraints from Year 3 data from the Subaru Hyper Suprime Cam Survey [Invited talk] Korea Astronomy and Space Science Institute, Daejeon, South Korea, October 2024.

Cosmological constraints from Year 3 data from the Subaru Hyper Suprime Cam Survey [Invited talk] 11th KIAS Workshop on Cosmology and Structure Formation, Gyeongju, South Korea, October 2024.

Astronomy and its use in the society [Invited talk] Institution of Engineers chapter, Nagpur, November 2024.

The Search for Planet Nine in the Outskirts of our solar system, IIST seminar, Trivandrum, January 2025.

Dipanjan Mukherjee

Simulating the impact of relativistic jets on galaxy evolution [Invited talk] Conference on Plasma Simulations, 2024, from 11-13 November at IIG, Mumbai.

AGN feedback studies with PLUTO2 [Invited talk] (online) PLUTO symposium 2024, from 23-25 September.

AGN feedback simulations [Invited talk] Seminar at Presidency University on August 07, 2024.

How relativistic jets from supermassive black holes shape galaxy evolution [Invited plenary talk] 39th National Symposium on Plasma Science and Technology, from December 17 - 20, 2024, at IPR, Gandhinagar.

Unveiling the role of relativistic AGN jets in galaxy evolution, seminar held at NISER Bhubaneswar, March 04, 2025.

Shreya Mukherjee

Cosmology with weak lensing cosmic shear: Dark energy and baryonic effects on matter power spectrum, poster presented at the 33rd Indian Association for General Relativity and Gravitation (IAGRG) 2025 conference, BITS, Pilani, Rajasthan, January 02 - 04, 2025.

Cosmology with weak lensing cosmic shear: Dark energy and

baryonic effects on matter power spectrum, talk presented at the fourth chapter of the Pune-Mumbai Cosmology and Astro-Particle (PMCAP) meeting, IIT, Bombay, February 07 - 08, 2025.

Cosmology with weak lensing cosmic shear: Dark energy and baryonic effects on matter power spectrum, talk presented at the 43rd Astronomical Society of India (ASI) meeting, National Institute of Technology, Rourkela, Odisha, February 15 - 19, 2025.

Sowgat Muzahid

Baryons Beyond the Luminous Boundaries of Galaxies and Clusters, colloquium at NCRA, Pune, April 2024.

Summary of IGM/CGM research in IUCAA, seminar at IUCAA, Pune, April 2024.

Vaidehi Paliya

Delivered two lectures in an IUCAA-sponsored workshop on High-Energy Astrophysics, organised by the Department of Physics, Banaras Hindu University, Varanasi, from 25-27 November 2024. The topics covered were *Introductory gamma-ray astronomy*, *Career prospects in astronomy*.

Aseem Paranjape

Delivered a lecture along with a hands-on session on *Computational Statistics in HPC settings* in the IUCAA-sponsored workshop on HPC at the University of Kashmir, Srinagar, during May 22-24, 2024.

Kanak Saha

Hunting the sources of cosmic reionization [Invited talk] Workshop titled Gravity@2024, Department of Physics, Cooch Behar Panchanan Barma University (ICARD), December 18, 2024.

Reionization of our Universe [Invited seminar] Department of Physics, North Bengal University (ICARD), December 16, 2024.

Key results from AstroSat UV Deep Field [Invited seminar] MPA, Garching bei Munchen, Germany, October 18, 2024.

Exploring the Cosmic Reionisation and galaxy growth with AstroSat [Invited seminar] CRAL, Lyon, France, October 15, 2024.

Probing galaxy formation using AstroSat [Invited talk] Workshop titled 'Probing stars and galaxies using innovative data science tools', Department of Applied Sciences, Guwahati University, September 04 - 06, 2024.

Deep field exploration with India's first astronomical observatory, AstroSat [Invited talk] SRM University, Sikkim, June 05, 2024.

Galaxy Science research at IUCAA, talk at the Scientific Advisory Committee meeting, IUCAA, April 22, 2024.

Varun Sahni

Reminiscences of Alexei Starobinsky and the Moscow school of Cosmology, Special evening lecture at Ashoka University, August 21, 2024, held on the occasion of the meeting "21st Century Cosmology: Tensions, Anomalies & New Physics".

Durgesh Tripathi

Linn Abraham et. al., Contributed Oral Presentation: *Galaxy Ring Detection* in AI/ML Applications in Astronomy & Astrophysics, IUCAA, Pune, January 09, 2025.

Linn Abraham et al., Contributed Oral Presentation: *Interpretable Deep Learning for Solar Flare Predictions* in Sun, Spaceweather and Solar-Stellar Connections, Indian Institute of Astrophysics, Bengaluru, January 20-24, 2025.

S. Pandit, Poster Presentation: *Investigating the Origins of Switchbacks in the Solar Corona* at the 125 years of KSO Sun, Space Weather, and Solar-Stellar Connections conference, Indian Institute of Astrophysics, Bengaluru, January 20-25, 2025.

J. Sarkar et al., Contributed Poster Presentation: *Results and Methods of the Test and Calibration of SUIT on board Aditya-L1*, in Sun, Space Weather and Solar-Stellar Connection Conference, Indian Institute of Astrophysics, Bengaluru, India, 2025. url: https://events.iiap.res.in/event/46/contributions/435/.

J. Sarkar et al., Contributed Oral Presentation: *Test and Calibration of the Solar Ultraviolet Imaging Telescope* in 6th Asia-Pacific Solar Physics Meeting, Guangzhou, China, Nov 11-15, 2024. url:https://apspm6.casconf.cn/.

J. Sarkar et al., Contributed Oral Presentation: *Photometric Calibration and Spectral validation of SUIT onboard Aditya-L1"* in 10th North-East Meet of Astronomers, Tezpur University, Assam, India. Oct 23-25, 2024.

J. Sarkar et al., Invited Oral Presentation: *Calibration of SUIT onboard Aditya-L1* in Aditya-L1 Teacher's Training Workshop, HBCSE-TIFR, Mumbai, India. March 03-05, 2024.

J. Sarkar et al., Invited Oral Presentation: *Calibration of SUIT onboard Aditya-L1* in 9th Aditya-L1 Science Workshop, IIT-Guwahati, India. March 24-26, 2024.

S. Roy et al., Contributed Oral Presentation: *Time evolution of thermal and non-thermal energies in Solar flares"* in Sun, Spaceweather and Solar-Stellar Connections, Indian Institute of Astrophysics, Bengaluru, January 20-24, 2025.

S. Roy et al., Invited Oral Presentation: *First observations from SUIT* in The European Solar Physics Online Seminars, March 27, 2025.

S. Pandit et al., Contributed Oral Presentation: *Long Term Solar Activity Using mm Indicators + Investigating the Origin of Switchbacks in the Solar Corona using Statistical Approach* in STCE

Seminar, Royal Observatory of Belgium, Brussels, Belgium, September 17, 2024.

S. Pandit et al., Contributed Oral Presentation: *Long Term Solar Activity Using mm Indicators + Investigating the Origin of Switchbacks in the Solar Corona using Statistical Approach* in Department of Physics, University of Helsinki, Finland, September 10, 2024.

S. Pandit et al., Contributed Oral Presentation: *Corona-Solar wind connection using new spacecraft data*, SRL Seminar, Department of Physics and Astronomy, University of Turku, Finland, September 9, 2024.

S. Pandit et al., Contributed Oral Presentation: *Long Term Solar Activity Using mm Indicators*, Institute Seminar, LPC2E, CNRS Orleans, France, August 28, 2024.

S. Pandit et al., Poster Presentation: *Investigating the Origins of Switchbacks in the Solar Corona*, in Sun, Space Weather, and Solar-Stellar Connection Conference, Indian Institute of Astrophysics, Bangalore, January 20-24, 2025.

D. Kathait et al., Contributed Poster Presentation: *Observations of Flare on 5th August 2023*, in 42nd meeting of the Astronomical Society of India (ASI), jointly hosted by IISc, ISRO, and JNP, Bengaluru, January 31 – February 5, 2024.

D. Kathait et al., Hands-on Session: "*Using SUIT/Aditya-L1 Data*" in The Seventh Aditya-L1 Support Cell Workshop, Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital, May 21–30, 2024.

D. Kathait et al., Contributed Poster Presentation: *Observations of Homologous Flares from AR 13386*, in Sun, Spaceweather and Solar-Stellar Connections, Indian Institute of Astrophysics (IIA), Bengaluru, January 20–24, 2025.

Durgesh Tripathi, Invited Lecture, *Aditya-L1: India's first space mission dedicated to solar observations*, Japan Geophysical Union Meeting, July 26-31, 2024.

Durgesh Tripathi, Keynote Lecture, *The Sun as seen through our own Aditya-L1*, International Conference on Gravitation, Astrophysics and Cosmology-2024, GLA University Mathura, June 13-15, 2024.

Durgesh Tripathi, Public Lecture, Himalayan Meet of Astronomers, *Aditya calling Aditya*, September 13-15, 2024.

Durgesh Tripathi et al., Invited lecture, *SUIT onboard Aditya-L1, Solar cycle variability: From understanding to making prediction,* Jointly organised by IIT BHU and ARIES, Nainital, October 14 -18, 2024.

Durgesh Tripathi, Award Lecture, *Coronal Heating and the Formation of the Solar Wind*, 6th Asia Pacific Solar Physics Meeting, November 11-15, 2024.

(j) LECTURE COURSE/WORKSHOP

Prakash Arumugasamy

Pulsars: Discovery and basics, Advances in Astronomy: Integrating Technology in Astronomy Research, April 04, 2024.

Detecting a pulsar in ORT voltage data, Advances in Astronomy: Integrating Technology in Astronomy Research, April 04, 2024.

Practical Statistics using Python, [2 lectures], Refresher Course on Astronomy and Astrophysics, May 13–14, 2024.

I*nformation and Communication Technology*, National Education Policy Orientation & Sensitisation Programme, May, July, & November 2024.

Pulsars, Radio Astronomy Winter School, December 19, 2024.

Anupam Bhardwaj

Delivered four lectures on *Stellar Structure and Evolution* during the Refresher Course on Astronomy and Astrophysics 2024, held concurrently with the online Summer School on Astronomy and Astrophysics from May 13 to June 14, 2024.

Debarati Chatterjee

Delivered two lectures (remotely) on '*Neutron Stars*' during ISSAA2023 (IUCAA Summer School / Refresher Course in Astronomy & Astrophysics) on June 12 and 13, 2024.

Subhadeep De

Quantum clock and its applications, Refresher Course: Recent Advances in Data

Science and Quantum Computing, Kannur University, 2024.

Quantum clocks, Introductory Summer School and Refresher Course in Astronomy & Astrophysics, IUCAA, 2024.

Gulab Chand Dewangan

High Energy Astrophysics, delivered three lectures at the Refresher Course and Summer School at IUCAA, May-June 2024.

Sanjeev Dhurandhar

Delivered two lectures on *Black Holes* at the Refresher Course/Summer School on May 30 - 31, 2024, IUCAA.

Delivered two lectures, *Gravitational Waves: An Overview I* and *Gravitational Waves: An Overview II,* on September 14 and 15, 2024, respectively, during the astronomy workshop, Shivaji University, Kolhapur.

Delivered three lectures on *Gravitational Waves* at the IUCAA Gravitational Wave Workshop, BITS-Pilani, Pilani, from October 15-19, 2024.

Rajeshwari Dutta

Interstellar Medium, delivered three lectures at the Refresher Course in Astronomy & Astrophysics, May 2024.

Ranjan Gupta

Delivered three lectures: *Telescopes \& their Mounts, Star magnitude and its motion*, and *Atmospheric Effect*, PAC Training Workshop, Positional Astronomy Center, Kolkata, March 03 - 07, 2025.

Sanjit Mitra

Delivered four lectures in the *GW Instrumentation Winter Workshop*, IUCAA, November 15, 2024.

Delivered four lectures in the *IUCAA Refresher Course & Summer School*, June 10-13, 2024.

Delivered three lectures and a hands-on session in the *High Performance Computing in Science* workshop, Kashmir University, May 22-24, 2024.

Delivered three lectures in the National Workshop on *Contemporary Issues in Astronomy and Astrophysics 2024* [CIAA-2024] held at the Department of Physics, Shivaji University, Kolhapur, September 13-15, 2024.

Surhud More

Lectures on *Gravitational lensing* at the IUCAA Summer School cum Refresher Course, IUCAA, June 2024.

Lectures on *Cosmology and Gravitational Lensing,* IUCAA workshop at Raisoni College, Nagpur, Maharashtra, July 2024.

Lectures on *Weak Gravitational lensing* at the RESCEU Summer school of the University of Tokyo, September 2024.

Lectures on *Cosmology and Gravitational Lensing*, IUCAA workshop at Malda College, West Bengal, November 2024.

Dipanjan Mukherjee

Delivered four lectures on *Radiative Transfer* and one lecture on *Computational Astrophysics* in the IUCAA Summer School in Astronomy and Astrophysics, June 2024.

Delivered one lecture in the Radio Astronomy Winter School at IUCAA [December 2024].

Sowgat Muzahid

Delivered a lecture on *Astronomical Techniques* during the Summer School in Astronomy and Astrophysics at IUCAA in May 2024.

Delivered a lecture on *Gas and metals around low-redshift galaxies and clusters*, Verenna, Italy, June 2024.

Delivered a lecture on *Galaxies: The building blocks of the universe,* Gauhati [online], March 2025.

Vaidehi Paliya

Delivered four lectures in an IUCAA-sponsored workshop on Active Galactic Nuclei organised by the Department of Physics, Presidency University, Kolkata, from July 22-23, 2024. The topics covered were Introductory AGN and High-Energy Radiative Processes.

Delivered one lecture on *Introductory Gamma-ray Astronomy* during the IUCAA Refresher Course in Astronomy and Astrophysics [May-June 2024].

Aseem Paranjape

Lecture course including three lectures and one hands-on session on Computational Statistics and Parameter Inference at the Department of Physics, IIT Hyderabad, during February 19-21, 2025.

Kanak Saha

Delivered three lectures during the Refresher Course and Summer School in Astronomy and Astrophysics, May 15-16, 2024.

Delivered lectures along with six days of hands-on training on a project at the Indo-French Astronomy School [IFAS-IX] on the subject: Galaxy dynamics with IFU data, Project: Measuring bar pattern speed using IFU observation, Chateau de Gotelas, France, October 04-11, 2024.

(k) POPULAR/PUBLIC LECTURES

Prakash Arumugasamy

Scales of the Universe, Astronomy, Science, and Society, April 19, 2024.

Understanding the changing sky, Astronomy, Science, and Society, September 03, 2024.

A feel for the Mass, Length, and Time scales in the Universe, Astronomy, Science, and Society, February 20, 2025.

Debarati Chatterjee

Gravitational Wave Astronomy [Invited talk] Frontiers in Physics XVIII at Fergusson College, Pune on February 11, 2025.

A new Era in Astronomy with LIGO-India, [public talk], Star Fest 2025 in Hingoli, February 5, 2025.

Unravelling cosmic mysteries with Gravitational Waves [Invited public talk] 'Meet an Astronomer' webinar organised by STEM and Space, January 9, 2025.

Gravitational Waves: A New Era in Astronomy, [Invited talk in Hindi]

Hindi Pakhwada celebrations at IUCAA, Pune, September 20, 2024.

Probing Extreme Physics with Gravitational Waves, [Invited popular talk], Space Technology Students' Society (spAts), Indian Institute of Technology, Kharagpur, August 24, 2024.

Current and future Gravitational Wave detectors [Invited public lecture], Basic Astronomy Course, Jyotirvidya Parisanstha (JVP), India, May 15, 2024.

Cosmic Symphony: Listening to the Universe with LIGO, delivered a talk as the Chief Guest for the National Astronomy Challenge felicitation event organised by STEM and Space, Pune, India, April 25, 2024.

Gravitational Waves: the game changer in Compact Star Astrophysics, SpaceCraft 2.0, Annual Science festival, Ashoka University, Sonepat, April 3, 2024.

Sourav Das

How did we know that the Earth revolves around the Sun? Talk delivered on the occasion of the National Science Day, IUCAA, India, February 28, 2025.

Susmita Das

The life and death of stars, talk delivered on the occasion of the National Science Day, IUCAA, India, February 28, 2025.

Subhadeep De

Usefulness of light in our day-to-day life (in Bengali), on the occasion of International Day of Light, Kolkata kalataan, Akashbani Moitrayee, 16 May 2024.

Gulab Chand Dewangan

AstroSat: India's effort on in space-based astronomical observations - A multi-wavelength cosmic vision, a public seminar at IIT Gandhinagar celebrating National Space Day, August 10, 2025.

Sanjeev Dhurandhar

Gravitational Waves: A Window to the Cosmos, public talk, BITS-Pilani, Pilani, October 19, 2024.

Neeraj Gupta

Massive radio survey reveals our universe at largest scales – MALS measurement of cosmic radio dipole, South Africa Broadcasting Corporation (SABC) TV News interview (September 2024).

MeerKAT ring of lights, South Africa Broadcasting Corporation (SABC) TV News interview (September 2024).

Sanjit Mitra

The future of Gravitational Wave Astronomy, IIT Bombay, March 31, 2024.

An overview of Gravitational Wave Astronomy and its fascinating challenges, VIIT, Pune, April 03, 2024.

Sneha Pandit

Life under the Sun: Exploring Habitability and Our Sun [in English and in Marathi - सूर्याभोवतीचे जीवन: अधिवासयोग्य ठिकाण्याच्या शोधात*]* delivered the second Saturday lecture at the Chandrasekhar Auditorium.

The Sun and the habitable zone delivered a talk at the Astronomy-themed program with the Maharashtra State Faculty Development Academy.

Life under the Sun: Exploring habitability and our Sun delivered a talk at the inauguration of the Nowrosjee Wadia College's Physics Club.

Kanak Saha

Exploring the Cosmic Reionization with India's AstroSat, delivered the first Chandra Lecture on the occasion of National Space Day Celebration at Chandrasekhar Auditorium at IUCAA, August 23, 2024.

(I) PROFESSIONAL ACHIEVEMENTS, MEMBERSHIPS AND OTHER RELATED DISTINCTIONS.

Anupam Bhardwaj

- Principal Investigator for an observing program on VLT-UVES of the European Southern Observatory, Germany (115.28AS, 30 hrs).
- Principal Investigator for an observing program on GeMS/GSAOI of the Gemini South Observatory, USA (GS-2025A-Q-217, 16.8 hrs).
- Principal Investigator for an observing program on VLT-HAWK-I of European Southern Observatory, Germany (113.26GQ, 6 hrs)

Debarati Chatterjee

- One of the leaders for Diversity, Equity and Inclusion (DEI) of the Gravitational Wave International Committee (GWIC) in 2025.
- Chair of the LOC and SOC for the International conference on Neutron star Equation of State and Gravitational waves (NEOSGrav2024), Goa, India, October 01-04, 2024.
- Chair of Education and Public Outreach, LIGO-India mega-science project from December 2020 to date.
- Member, Teaching Programmes Committee at IUCAA from September 2023 to date.

- Member of the Working Group for Gender Equity (WGGE) of the Astronomical Society of India (ASI) from 2020 to date.
- Invited as a panellist for the panel discussion "Unsolved problems in physics in the 21st century" during the India Science Festival at Fergusson College on January 11, 2025.

Susmita Das

Co-chair of the Executive Committee WG Junior Members, International Astronomical Union.

Subhadeep De

Patents and Trademarks

- ***Coherent optical fiber for in-phase photon transfer***', S. Johnson, S Dasgupta, S. Banerjee, A. Gangwar, and S. De, Indian Patent application no 202321045035 A, Filing date - 05/07/2023.
- Trademark '***PhotonSync***', Acceptance date – 03 January 2025 by Intellectual Property India.
- Organiser and Convener, The LIGO-India Detector All-hands Meeting held from December 10 - 11, 2024, at IUCAA.

Neeraj Gupta

- Principal Investigator: MeerKAT Absorption Line Survey (MALS).
- Co-Chair of the SKA International HI Working Group.
- Co-Chair of the Pulsars and HI Absorption Science Working Group: Hydrogen Intensity and Real-time Analysis eXperiment (*HIRAX*).
- Member of the Pipeline Calibration and Science Verification Working Group: 4MOST AGN survey.
- SOC member, IAU GA Symposium: Neutral hydrogen in and around galaxies in the SKA era, 2024 (August), Cape Town, South Africa.
- SOC member, IAU GA Focus meeting: The future of radio astronomy in an increasingly crowded spectrum, 2024 (August), Cape Town, South Africa.

Shasvath Kapadia

- Nominated for the IAGRG NR-Sen award by Profs. P. Ajith, K.G. Arun and Bala Iyer.
- Principal coordinator and co-developer of the gravitational-wave instrumentation workshop conducted from November 10 - 29, 2024. A total of 15 students (upper-undergraduate, masters and early Ph.D.) from all over India were selected. Four gravitational-wave instrumentation experts from IUCAA acted as resource people.

Aseem Paranjape

- Appointed as a regular associate of ICTP, Trieste, January 01, 2023, to December 31, 2028.

Kanak Saha

- Visiting Professor during May - July 2024 at the Cooch Behar Panchanan Barma University, West Bengal.

SCIENTIFIC MEETINGS AND OTHER EVENTS

Meeting of the Scientific Advisory Committee

The Scientific Advisory Committee (SAC) meeting of IUCAA was held from April 22-26, 2024. The Committee consists of **Professor Phil Charles** (University of Southampton; Chair), **Professor Priyamvada Natarajan** (Yale University; Member), **Professor T. R. Seshadri** (Delhi University; Member), **Professor Ravi Sheth** (University of Pennsylvania: Member), **Professor Luc Simard** (University of Victoria; Member), **Professor P. Sreekumar** (Manipal Centre for Natural Sciences; Member), **Professor Alan Weinstein** (California Institute of Technology; Member) and **Professor R. Srianand** (Director, IUCAA; Member Secretary). Professor Priyamvada Natarajan could not attend the meeting.

The Committee received reports and presentations by faculty on all aspects of the activities of the Centre. The SAC members were given science presentations by a wide range of speakers from IUCAA and Associates. The SAC also had informal interactions with IUCAA's scientific staff, graduate students, postdoctoral fellows, visitors and personnel from the administration. The SAC members, in their report, were very impressed with the accomplishments made by IUCAA in terms of fulfilling their mandate of bringing astronomical research and education opportunities to a wider geographical spread of Indian universities. They also provided various suggestions and recommendations to sustain and improve various activities of the Centre. IUCAA is in the process of developing a road map to implement these recommendations well ahead of the next SAC meeting scheduled two years from now.

(For details, see Khagol 133, July 2024)

Refresher Course on Astronomy and Astrophysics and the online Summer School on Astronomy and Astrophysics

The Refresher Course on Astronomy and Astrophysics 2024 was held at IUCAA from May 13 - June 14, 2024. It was held concurrently with the Online Summer School on Astronomy and Astrophysics. There were eighteen faculty participants from higher educational institutions located across the country. The lectures covered a wide range of topics, introducing the basic and advanced topics of the field, which included introductory astronomy, optical astronomy techniques, radio astronomy, radiative processes, stellar structure and evolution, the Sun, galaxies, interstellar medium, active galactic nuclei and jets, gamma-ray astronomy, compact objects, black holes, neutron stars and pulsars, gravitational lensing, high-energy astrophysics, fluids and plasmas, gravity, general theory of relativity and cosmology, structure formation.

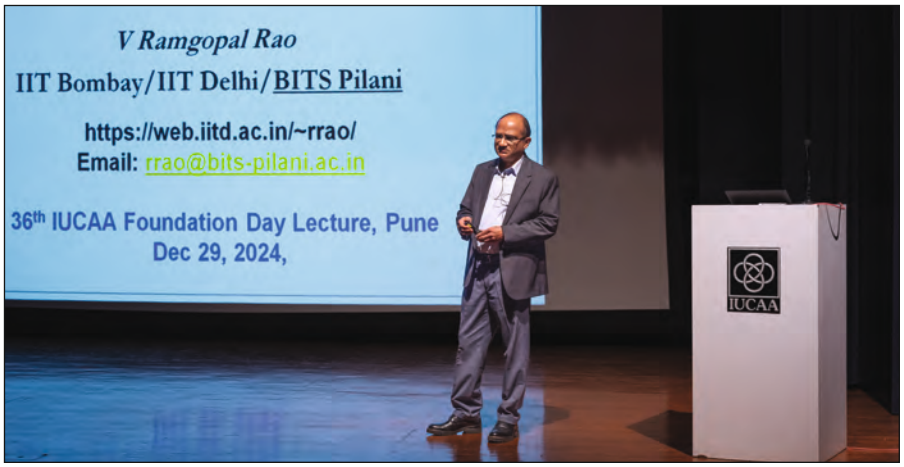
The sessions were conducted by faculty members, scientific staff, postdoctoral fellows and research scholars of IUCAA. The Refresher Course was coordinated by Rajeshwari Dutta and Team ACE IUCAA.

(For details, see Khagol 133, July 2024)

Visit Report: French Consul General and Consular team at IUCAA

The French Consul General and Consular team, Mr. Jean-Marc Séré-Charlethe, French Consul General in Mumbai, and Dr. Philippe Maurinthe, the French Science and Higher Education Attaché, visited IUCAA on 22 July 2024. The visit aimed to explore the potential Indo-French collaborations in scientific research and innovation. The critical focus areas discussed included collaborative initiatives such as CEFIPRA, Space-astronomy-related projects, student exchange programs, and France's Year of Innovation for 2026.

(For details, see Khagol 134, October 2024)



The Thirty-Sixth Foundation Day Lecture

The 36th Foundation Day Lecture was delivered on December 29, 2024, by Prof. V. Ramgopal Rao, Group Vice-Chancellor for the Birla Institute of Technology & Science (BITS) Pilani campuses located in Pilani, Hyderabad, Goa, Dubai and Mumbai. Prof. Rao's talk was titled Unleashing India's Scientific Potential: Breaking Barriers and Igniting Innovation. The recorded lecture is available at the YouTube link: https://www.youtube.com/watch?v=z7Jm_SzEHC8

(For details, see Khagol 135, January 2025)

NATIONAL SCIENCE DAY 2025

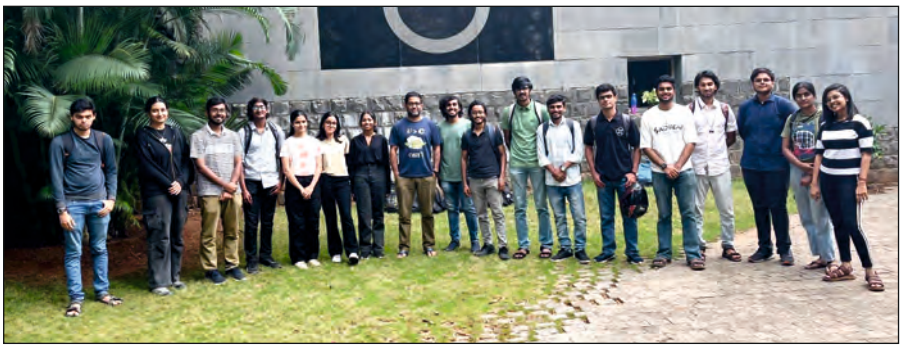
National Science Day 2025

The National Science Day was celebrated with an Open Day on February 28, 2025, at IUCAA and other events throughout February. Like every year, IUCAA responded to people's enthusiasm to associate better with Science and Scientists. The celebrations attracted numerous students from Pune and other parts of Maharashtra, including teachers, parents and the public.

(For details, see Khagol 136, April 2025)

GW Open Data Workshop (ODW) by the LIGO-Virgo-KAGRA collaboration

The IUCAA chapter of the 'GW Open Data Workshop' was organised by the Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, and took place over three days from April 18 - 20, 2024, at IUCAA, Pune. The workshop was an ongoing effort by the LIGO-India scientific collaboration members of IUCAA to provide local college and university participants in Pune with a detailed understanding of gravitational wave data analysis techniques. This was the third consecutive year of organising a workshop in sync with the main Gravitational Wave Open Data



Workshop organised by the LIGO-Virgo-KAGRA collaboration. The workshop was coordinated by Apratim Ganguly and Sanjit Mitra.

(For details, see Khagol 133, July 2024)

Tutorial on IGWN-DHTC-OSG

A three-day-long tutorial on Introduction to the International Gravitational Wave Network, Distributed High-Throughput Computing and Open Science Grid was held at IUCAA from September 09 - 11, 2024. The tutorial focused on addressing the data analysis and computing requirements of the LIGO-India Scientific (LISC) community members. Miron Livny, the Principal Investigator of the HTCondor / OSG / PATh project and his HTCondor Software Suite team members, Greg Thain and Rachel Lombardi, from the University of Wisconsin-Madison, USA, along with Siddharth Mohite, Computational Scientist, Pennsylvania State University, USA, conducted the tutorial. The tutorial was organised by Sandeep Joshi and Sanjit Mitra.

(For details, see Khagol 134, October 2024)

Gravitational-Wave Instrumentation Workshop

The Gravitational-Wave Instrumentation Workshop (GWIW) was held from November 10-29, 2024. The workshop introduced upper undergraduate and graduate students to GW instrumentation, focusing on various subsystems of the LIGO GW detector. The workshop took a novel approach, where a large portion of the participants' time was spent in IUCAA's in-house laboratories hosted in SITARA.
The workshop was coordinated by Shasvath J. Kapadia.

(For details, see Khagol 135, January 2025)

Baryons Beyond Galactic Boundaries - 2024

The week-long international conference "Baryons Beyond Galactic Boundaries" was organised at IUCAA, Pune from December 02-06, 2024. The primary objective was to bring together leading experts and emerging researchers focused on investigating the diffuse baryons in the Circumgalactic Medium (CGM) and Intergalactic Medium (IGM). The conference aimed to explore these topics through various observational techniques and hydrodynamical simulations. It offered a comprehensive review of the field's advancements over the past two decades and discussed its future directions. The conference was attended by 89 participants, nearly half of whom travelled from abroad. The conference was coordinated by Sowgat Muzahid and R. Srianand.

(For details, see Khagol 135, January 2025)

LIGO India All-hands

The LIGO-India project received approval from the Union Cabinet of India, and the detector is expected to start science runs by 2030. It promises a massive boost in science and technology. This mega-science project requires multidisciplinary expertise in vacuum technology, lasers & optics, quantum metrology, sophisticated electronics, data acquisition-cum-control, data handling, high-performance computing, etc. The detector building, including construction for housing the detector, is very complex; keeping that in mind, a project execution team have been identified with the distribution of work among them. Therefore, detector building demands collaboration among team members and extending among national and international institutions and universities to bring experts in this wide range of fields together and work together cohesively. IUCAA, being one of the lead institutions for executing the project, organised an all-hands meeting at its premises on December 10-11, 2024, inviting all the project execution team members for planning and discussion. The meeting was organised by Subhadeep De.

(For details, see Khagol 135, January 2025)

17th Radio Astronomy Winter School

The 17th edition of the annual Radio Astronomy Winter School (RAWS) was organised jointly by IUCAA and NCRA–TIFR from December 14-24, 2024. Twenty-seven student participants were selected among more than 560 applications received. The educators, ten in all, comprised faculty members, research scholars, post-doctoral fellows, and scientific staff interested in adopting radio astronomy concepts and experiments in their college-level course curricula. The students were second and third-year undergraduates who had been introduced to radio astronomy for the first time. The organising committee comprised Ashish Mhaske, Avinash Deshpande, Dhruba J Saikia, Jameer Manur, Prakash Arumugasamy, and Rajeshwari Dutta, all from IUCAA and Subhashis Roy from NCRA-TIFR.

(For details, see Khagol 135, January 2025)

2nd Daksha Workshop: Indian Eyes on Transients Skies

The Second Daksha Science Workshop was held at the Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, on March 29-31, 2025, in a hybrid format. The workshop successfully brought together a wide audience, comprising about seventy participants attending in person and over a hundred joining virtually. The event received an enthusiastic response from the scientific community and served as a vibrant platform for the exchange of ideas and ongoing research related to the Daksha mission. The workshop was coordinated by Gulab Dewangan (IUCAA) and Varun Bhalerao (IIT, Mumbai).

(For details, see Khagol 136, April 2025)

IUCAA Workshop on AI/ML Applications to Astronomy & Astrophysics (AMAA)

The IUCAA workshop on AI/ML in Astronomy and Astrophysics (AMAA) was held from January 6-10, 2025. It was jointly organised by Ajit Kembhavi (IUCAA) and Arif Babul (University of Victoria, Canada). The primary objective of the workshop was to foster collaboration among researchers in India and abroad working on the rapidly evolving field of machine learning applications in astronomy, astrophysics, and related areas. The workshop was coordinated by Arif Babul (Univ. of Victoria, Canada) and Ajit Kembhavi (IUCAA, Pune).

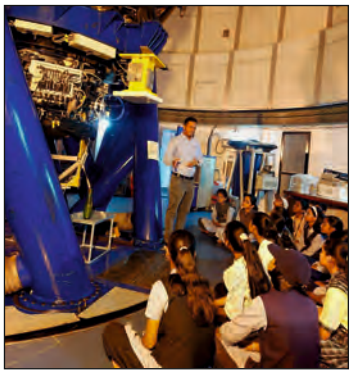
(For details, see Khagol 136, April 2025)

PUBLIC OUTREACH HIGHLIGHTS

Summer Astronomy Camps

Summer Astronomy Camps were conducted at IUCAA in three batches during the dates listed below:

- April 29 - May 03, 2024
- May 06 - 10, 2024
- May 14 - 16, 2024 (Rural)



National Space Day Celebrations

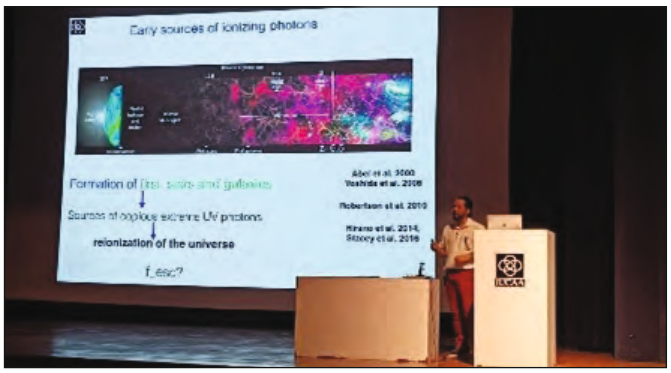
IUCAA conducted and collaborated on various outreach events across the country to mark the first nationwide celebration of **National Space Day**:

August 21, 2024: Samir Dhurde delivered two talks— *"India and Space Astronomy"* at IIT Dhanbad, and *"Space Astronomy"* for teachers at the State Council for Educational Research and Training (SCERT), Bihar.

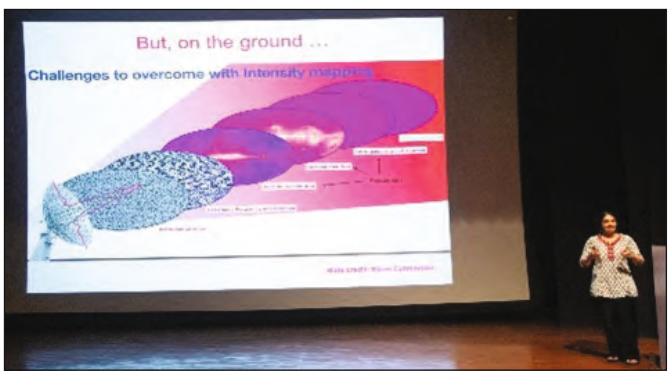
August 23, 2024: A **National Space Day Exhibition** was organised in collaboration with the Department of Physics, Savitribai Phule Pune University (SPPU), for school and college students.

Chandra Public Lectures

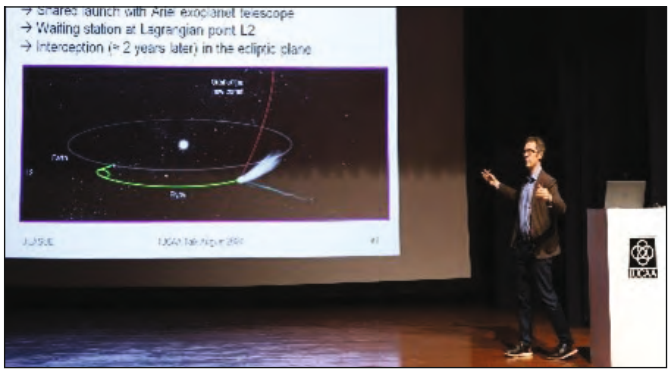
The public talk series at IUCAA has been renamed **"Chandra Public Lectures"** in honour of **Prof. Subrahmanyan Chandrasekhar**, after whom the venue — the **Chandrasekhar Auditorium** — is also named. The following talks were conducted as part of this series:



August 23, 2024: **Kanak Saha** delivered a lecture titled '***Exploring the Cosmic Re-ionisation with India's AstroSat***'.



September 26, 2024: **Hamsa Padmanabhan** (University of Geneva) gave a lecture titled '***Mapping the First Billion Years: Secrets from Our Invisible Universe***'.



August 29, 2024: **Jérémie Lasue** (IRA, France) presented a talk titled '***The European Space Exploration of Comets: From Giotto to Comet Interceptor***'.

As part of IUCAA's broader public engagement initiatives, two additional Chandra Public Lectures were delivered:

1. **Arif Babul** (University of Victoria, Canada) presented a lecture titled '***How Did the Universe Come to Look the Way It Does?***'.
2. **Michitoshi Yoshida** (Vice-Director General, National Astronomical Observatory of Japan) delivered a talk titled '***Striking Gold with Gravitational Waves***'.

2nd Saturday Lecture / Demonstration Series

A fresh round of the 2nd Saturday Lecture/Demonstration series was initiated in line with the new school academic session. IUCAA continued its monthly public engagement through this series with the following talks and demonstrations:

July 13, 2024: *"Decoding Our Universe Through Spectroscopy"* by **R. Srianand** [English].

August 10, 2024: *"Exploring Habitability and Our Sun"* by **Sneha Pandit** [English & Marathi].

September 14, 2024: *"Cosmic Dawn: Birth of the First Stars"* by **Atrideb Chatterjee** [English].

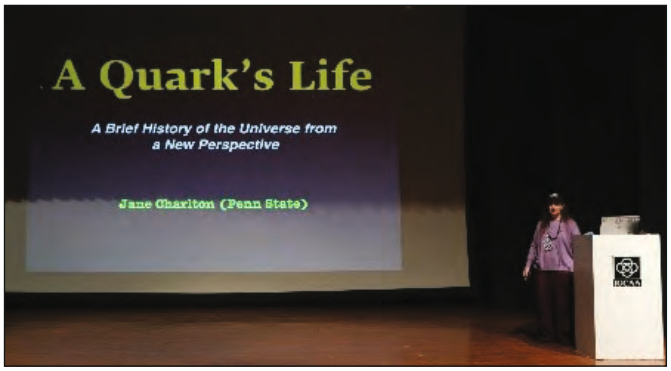
Additional talks and demonstrations held under this series include:

- *"Studying the Universe from Space"* by **Varun Bhalerao** [IIT Bombay]
- *"A Quark's Life: A Brief History of the Universe from a New Perspective"* by **Samir Dhurde** and the **SciPop Team**
- *"Astronomy, Artificial Intelligence, and the Future"* by **Ashish Mahabal** [Caltech, USA]
- *"The Science of Flight"* – a demonstration session by **Madhav Khare**, Founder and Trustee, **Shastravahini, Pune**

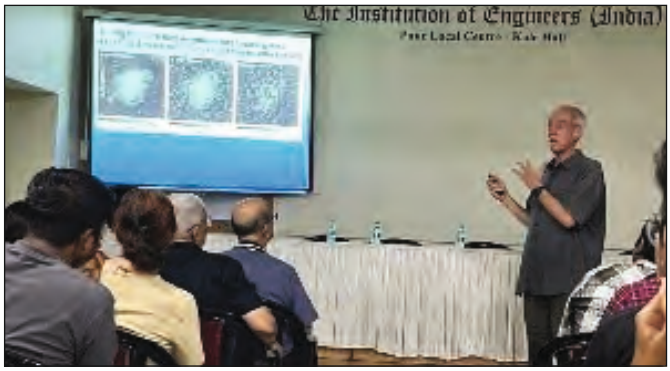
In-Reach Activities for IUCAA Members:

September 19, 2024 – A special hands-on session on DIY Spectroscopy was initiated by Debarati Chatterjee and Samir Dhurde and conducted by the SciPop team for IUCAA-NCRA Graduate School students. Sixteen students participated, gaining practical experience in constructing low-cost, effective spectroscopes and using them to observe real spectra. The session also introduced the students to IUCAA's outreach programmes, sparking interest in their future involvement.

November 21, 2024: Talk by Nigar Shaji [ISRO, Bengaluru] titled *"A Vision for Future Indian Space Missions"*.



December 03, 2024: Talk by Jane Charlton (Penn State University, USA) titled '*The Life of a Quark*'.



December 05, 2024: Talk by Lutz Wisotzki (Leibniz-Institut für Astrophysik Potsdam (AIP) titled '*The Cosmic Time Machine – What the Light from Distant Galaxies Can Tell Us*'. This talk was organised in collaboration with Jyotirvidya Parisanstha.

(Photo credits: JVP, Pune)

January 02, 2025: A special session for IUCAA Post-Doctoral Fellows featured an interactive discussion on outreach opportunities, followed by a skywatch session. The event aimed to encourage greater engagement in public science communication among early-career researchers.

Public Astronomy Events

Mar 28, 2025: Messier Marathon, Parut Village, Mahabaleshwar (10 amateur astronomers).

IAU-Related Outreach

Samir Dhurde actively participated in and conducted workshops at several events supported by the International Astronomical Union (IAU) Office of Astronomy for Education (OAE):

- **IAU OAE FRESCO Residency Meeting** (October 13–15, 2024) held in Istanbul, Turkey, where two new astronomy board games were developed. These games are currently being tested by IUCAA's SciPop team with various school audiences across India.
- **Mediterranean Regional SHAW-IAU Workshop on Astronomy for Education (MASTED)** (October 16–20, 2024) in Istanbul, Turkey.
- **1st Asian Regional SHAW-IAU Workshop on Astronomy for Education 2024** (December 19–21, 2024) held in Kathmandu, Nepal.

As a co-National Outreach Coordinator (co-NOC) for India under the IAU, Samir Dhurde contributed to the international **"Equal Day"** pilot events on March 20, 2025. Supported by the IAU OAE, this global initiative registered 135 events worldwide and marked a significant milestone in promoting astronomy education and public engagement.

In addition, Samir participated in **Nakshatra Sabha**, an astro-tourism event, where he delivered a talk titled **"Dark Sky Conservation: Current Worldwide Efforts and Challenges."** The session highlighted global initiatives and challenges related to preserving dark skies, addressing issues such as light pollution and advocating sustainable skywatching practices.

Outreach for Associates and ICARDs

As part of its outreach support for Associates and ICARDs, IUCAA facilitated several educational initiatives across the country:

- A **Basic Astronomy and Telescope Making Workshop** was held on January 11–12, 2025, at St. Claret PU College, Bengaluru. Proposed by S. B. Gudennavar (ICARD, Christ University), the workshop was conducted by Samir Dhurde and Tushar Purohit. It engaged 70 students and 10 teachers and successfully resulted in the making of 23 telescopes.
- During **Astro Week** at IIT Gandhinagar, organised by Anand Sengupta, Samir Dhurde delivered a lecture and led amateur astronomy activities, including a public Skywatch attended by approximately 200 participants.
- Another **Telescope-Making Workshop** was organised from March 19–21, 2025, by Prof. Hemwati Nandan (HNB Garhwal University). Maharudra Mate and Tushar Purohit conducted the sessions, guiding 63 students and 5 teachers in building and testing four telescopes.

Teacher Workshops & Special Training

Jul 18–19, 2024: Maratha Vidya Prasarak Samaj, Nashik (20 teachers)

Aug 23–24, 2024: Rural Teachers, Ambegaon at IUCAA (30 teachers)

Jan 17–18, 2025: Annasaheb Awate College, Manchar (40 teachers)

Jan 22, 2025: SVS High School, Khadki (25 teachers)

Feb 05, 2025: EduConclave 2.0, Pune Knowledge Cluster (35 teachers)

Feb 05, 2025: LIGO-India Starfest, Hingoli (35 teachers)

Special Interactions & Talks:

Sep 19, 2024: DY Patil College Astronomy Club (25 students)

Mar 04, 2025: Talk on Research at IUCAA, Annasaheb Awate College, Manchar.

Astronomy Workshops:

Apr 27, 2024: G. H. Raisoni College of Engineering and Management, Wagholi (50 students)

Oct 10, 2024: Modern College of Engineering, Pune (50 students)

Nov 19, 2024: Bhaktivedanta Model School (40 students)

Nov 25, 2024: Mahilashram Junior College (50 students)

Dec 17, 2024: Vibgyor School (33 students)

Jan 02, 2025: C.T. Bora College, Shirur (500 students and teachers)

Jan 09, 2025: S.P.S. College of Education, Sangli (50 students)

Mar 04, 2025: DIET Teachers, Palghar (25 teachers)

Mar 17, 2025: DIET Teachers, Satara (37 teachers)

Mar 19, 2025: DIET Teachers, Chhatrapati Sambhajinagar (25 teachers)

Mar 19, 2025: DIET Teachers, Nanded – Batch I (72 teachers)

Mar 25, 2025: DIET Teachers, Nanded – Batch II (72 teachers)

Feb 05, 2025: EduConclave 2.0, Pune

Skywatch / Sky Observation Sessions

Nov 27, 2024: MIT Gurukul World School, Loni (350 participants)

Jan 10, 2025: T.C. College, Baramati (550 participants)

Jan 11, 2025: Ratnai Mahila Mahavidyalaya, Rajgurunagar (85 participants)

Jan 24, 2025: Centre for Science Education & Communication (500 public)

Jan 24, 2025: Avasara Academy, Pune (90 students and teachers)

Feb 03, 2025: Panchayat Samiti, Wai (600 students and teachers)

Feb 03, 2025: V.P.'s Vinodkumar Gujar Bal Vikas Mandir, Baramati (950 participants)

Feb 08, 2025: Podar International School, Kolhapur (2,500 participants)

Mar 26–27, 2025: Rajiv Gandhi Academy of e-Learning (Sky Observation included)

Science Toys Workshops

Apr 08, 2024: D. G. Walse Patil School, Pargaon (68 students)
June 13, 2024: Saraswati Vishwa Vidyalaya, Nigdi (60 students)

Sep 03, 2024: Euro School, Wakad (83 students, 6 teachers)

Sep 12, 2024: Hill Green School, Undri (102 students, 4 teachers)

Sep 27, 2024: ZP Teachers, at IUCAA (270 teachers, Akanksha Foundation)

Oct 15, 2024: The Kalyani School, Pune (60 students and teachers)

Oct 21–24, 2024: Sainik School, Goalpara, Assam (700 students, 20 teachers)

Nov 28, 2024: Sondara School, Domari, Beed (45 students, 5 teachers)

Dec 19, 2024: Dnyandeep Vidyamandir, Dapoli (80 students, 5 teachers)

Jan 09, 2025: S.P.S. College of Education, Sangli (Science Toys & Astronomy)

Mar 08, 2025: SRPF, Daund (500 people)

Telescope-Making Workshops

Apr 15, 2024: Ashoka Universal School, Nasik (20 students)
Apr 27–28, 2024: St. Xavier's School, Sardhana, Meerut (50 students)

May 01, 2024: St. Xavier's School, Meerapur, Prayagraj (40 students)

May 24, 2024: At IUCAA (16 participants made 7 telescopes)

May 30, 2024: At IUCAA (4 students)

June 03–08, 2024: Ashoka University, Sonipat (33 students, 33 optical + 5 radio telescopes)

Jul 26–27, 2024: JRD School, Akola (50 students, 5 teachers)

Aug 13, 2024: Shiv Nadar Schools, New Delhi (30 students, 5 teachers)

Sep 22, 2024: IIT (ISM), Dhanbad (30 students, 10 teachers)

Oct 07–08, 2024: St. Xavier's College, Ahmedabad (200 students, 20 teachers)

Oct 15–17, 2024: IAPT, Dharamshala (30 students, 5 teachers)

Oct 21–24, 2024: Sainik School, Goalpara, Assam

Nov 22, 2024: Ashoka University, at IUCAA (70 teachers)

Dec 10, 2024: KBT College of Engineering, Nashik (35 teachers)

Jan 13, 2025: Shibumi School, Bengaluru (80 students, 4 teachers)

Jan 27–28, 2025: KTHM College, Nashik (140 teachers)

Mar 26–27, 2025: Rajiv Gandhi Academy of e-Learning (10 students, 2 teachers)

National Science Day 2025

IUCAA celebrated **National Science Day 2025** with a series of engaging outreach activities throughout February, culminating in a vibrant **Open Campus Day** on **February 28**, themed *"Science & Innovation at IUCAA."* Over **7,000 visitors** from across Maharashtra participated.

The Open Campus Day featured:

- Live demos, hands-on exhibits, and public talks across the IUCAA campus.
- Attractions like the Foucault Pendulum, solar observations, quantum science demos, and exhibits on LIGO-India, ADITYA-L1, and AstroSat.
- A special aeromodelling show by Madhav Khare.
- Multilingual public lectures by researchers and an "Ask a Scientist" session.
- School-level exhibits, science puzzles, and storytelling by Prof. Jayant Narlikar.
- A public Skywatch event at the SPPU sports ground, which drew large crowds.

Preceding events included:

- Competitions for rural students on **February 01, 2025,** at Awasari, involving fifteen schools.
- Inter-school science competitions in Pune on **February 22, 2025**, with 180 students from thirty-six schools.
- A special "Human Orrery" demo for teachers by Emmanuel Rollinde and Surhud More.

The celebrations successfully fostered public engagement, scientific curiosity, and student participation across age groups.

(For details, see Khagol 133, 134, 135 and 136)

Office of Astronomy for Education (OAE) Center – India

Activities undertaken during April – June 2024

Objective: Professionalise astronomy education

The IAU OAE office called for teacher training proposals (TTP) from teachers and astronomers worldwide.

Objective: Provide access to good resources: Resource Translations:

The Big Ideas book has been translated into Marathi by OAE Center India.

New Resources:

The OAE Center India is involved in making astronomy glossary cards containing the IAU astronomy glossary and related images.

Objective: Promote astronomy in curricula:

The OAE Center India finished the project of the baseline survey in Astronomy, where the status of astronomy education among school students was analysed.

(Khagol 133, July 2024)

Activities undertaken during July – September 2024

Objective: Professionalise astronomy education

The OAE, India Center assisted the IUCAA SciPop team in organising a Teachers' Training workshop on the campus during August 23-24, 2024. The workshop was attended by thirty teachers from rural areas in the state and comprised lectures, hands-on activities, and sky observations. A lecture on the lifecycle of stars was delivered during the program.

Objective: Provide access to good resources: Resource Translations:

The OAE Center - India undertook the English translation of the Marathi book titled 'Khagol Goshthi'(on positional astronomy). The Center completed the review of the Marathi version of the book 'Big Ideas' and plans to print copies for distribution in the schools.
Distribution of Resources:

The OAE Center - India team has created user guides for the books 'Big Ideas in Astronomy', 'Khagol Goshti', and 'Jantar Mantar' to assist the teachers in using the books effectively in class. The Center has distributed approximately 100 sets of Marathi books in the schools. They have received a request for three hundred books, which is in the process of distribution.

Objective: Promote astronomy in curricula:

The OAE Center - India conducted a baseline survey for the status of astronomy education throughout the country over the last year and the manuscript based on the results is currently under peer review. The OAE Center - India is working on the analysis of the survey data to investigate the differences in astronomy education among different states of India. The preliminary results show there is a large variance in the understanding of astronomy concepts and the availability of resources among the states. The Center also conducted a public astronomy survey during the Science Day activities over the past two years. The data analysis will help understand the public perception of astronomy and prepare a manuscript on the same.

Objective: OAE Networking:

The OAE Center - India assisted in the organisation of the 6th SHAW IAU workshop (A virtual international workshop held from November 12 - 15, 2024). Also, as a part of the Astronomy Education Research Scientific Organising Committee, the OAE Center - India team reviewed the submitted abstracts and helped to create the program. The Center also volunteered for the JWST session of the workshop.

(Khagol 134, October 2024)

Activities undertaken during October – December 2024

The OAE Center India funded three teacher training workshops from October to December 2024, at Tiruchirappalli, Tamil Nadu, Nainital, Uttarakhand, and Nehru Planetarium, Mumbai, Maharashtra. The workshops benefited a number of teachers, and all of them included pedagogical as well as practical aspects of teaching astronomy in schools.

The office printed several sets of three astronomy books for school students: '*Big Ideas in Astronomy*'(in English and Hindi), 'Khagol Goshti' (Astronomy Tales - in Marathi), and 'Jantar Mantar' (Historic Indian Observatory - in English, Hindi, and Marathi). These books, together with user guides for teachers on how to use these books in their classes effectively, have been distributed in about four hundred schools. The office also completed an English translation of the book '*Khagol Goshti*', which is now at the vetting stage.

Our team performed a secondary analysis of the baseline survey on Astronomy education in order to assess state-to-state differences and similarities within India. We observed substantial disparities in performance across states. The insights gained offer important implications for comparing state-level teaching standards and guiding the development of a more effective national astronomy curriculum. These results were presented at the epiSTEME-10 conference held at HBCSE, Mumbai, and the summary of this work will be published in the conference proceedings.

Finally, the OAE Center India also helped in the organisation of the annual SHAW IAU workshop this year, with members acting as part of the SOC of the Astronomy Education Research part as well as in the technical organisation of the workshop.

(Khagol 135, January 2025)

LIGO-India Education and Public Outreach (LI-EPO)

LIGO-India is an upcoming gravitational wave detector in India, set to join the global network of gravitational wave observatories, which includes LIGO (USA), Virgo (Europe), and KAGRA (Japan). This mega-science initiative aims to construct a 4 km × 4 km "L"-shaped interferometer in the Aundha-Nagnath Taluka of Hingoli District, Maharashtra. The project is being developed under the aegis of the Department of Science and Technology (DST) and the Department of Atomic Energy (DAE), Government of India, through a Memorandum of Understanding with the National Science Foundation (NSF), USA. The four principal institutes involved in the LIGO-India project are the Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune; the Directorate of Construction, Services and Estate Management (DCSEM), Mumbai; the Institute for Plasma Research (IPR), Gandhinagar; and the Raja Ramanna Centre for Advanced Technology (RRCAT), Indore. The LIGO-India Education and Public Outreach (LI-EPO) program is committed to nurturing a vibrant community of young individuals interested in the interdisciplinary field of gravitational wave science. One of its key goals is to inform students in STEM fields about career opportunities within this

emerging domain. LI-EPO also bridges the gap between scientists and the general public through interactive talks, public events, and participation in national science festivals. Furthermore, the program actively engages with the residents of Hingoli, where the detector is being built, to raise awareness and ensure local involvement, while also advocating the project's significance to policymakers and stakeholders.

Categories of Outreach

LIGO-India's outreach activities are broadly classified into four categories:

- National Outreach: Promoting awareness of gravitational wave astronomy and LIGO-India across the country and encouraging students to pursue careers in this field.
- Hingoli Outreach: Building strong connections with the local Hingoli community and keeping them well-informed about the project's developments.
- Social Media Outreach: Using online platforms to disseminate information and highlight career opportunities to the youth.
- International Outreach: As part of a global network of gravitational wave observatories, LIGO-India collaborates with LVK-EPO groups to plan joint outreach initiatives.

Key Outreach Activities

LIGO-Livingston Virtual Tour

With contributions from Gaurav Waratkar (Ph.D. scholar, IIT Bombay), Shreejit Jadhav (Postdoctoral researcher, Swinburne Institute of Technology), and William Katzman (LIGO Science Education Center), a Marathi-language virtual guided tour of the LIGO-Livingston facility was developed. Specifically tailored for the Hingoli audience, this video helps visualise what the upcoming detector will resemble. Released in January 2025 via LIGO-India's YouTube and social media platforms, the video has been showcased at multiple outreach events in Hingoli and national science festivals.

Hingoli Rural School Outreach

Recognising the vital role of young minds in shaping the future of mega-science projects, LI-EPO organised two school outreach programs in Hingoli since January 2025. The team visited the APJ Abdul Kalam Lab at a Zilla Parishad school and another rural ZP school. In these interactive sessions, students learned about the LIGO-India project, gravitational wave science, and had the opportunity to ask questions. These efforts continue the tradition of engaging rural schools in the region.

Hingoli Star Fest

On February 5, LI-EPO organised a Star Fest in Hingoli, attended by over 150 teachers and astronomy enthusiasts. The event supported the creation of Khagol Manch (amateur astronomy groups) in each Taluka of Hingoli, which will regularly host astronomy events and make use of donated telescopes. With the presence of the District Collector and CEO of Hingoli, one Newtonian telescope (donated through Newton-Bhabha funds), two refractor telescopes, and a *Listening to the Universe* pop-up book in Marathi were distributed to each Khagol Manch. The fest featured a Q&A with GW scientists from IUCAA - Sudhir Gholap and Debarati Chatterjee - followed by an astronomy lecture, hands-on telescope handling sessions, and a stargazing event that brought the night sky to life for the attendees.

Fergusson College Outreach

Debarati Chatterjee (IUCAA) and Saurabh Salunkhe (IUCAA) were invited to present a special session on LIGO-India and its outreach activities at the *Frontiers in Physics* conference at Fergusson College, Pune, on February 12. Their interactive talks covered the fundamentals of gravitational wave science and discussed the diverse career opportunities offered through the LIGO-India project.

National Science Day at IUCAA

On February 28, IUCAA celebrated National Science Day, honouring Dr. C.V. Raman's contributions to science. The LI-EPO team set up an engaging booth focused on gravitational wave science. Several models and demonstrations were showcased, including:

- A perihelion shifts model of Mercury to illustrate the difference between Newtonian and Einsteinian gravity
- A scaled-down model of the LIGO-India detector
- A gravitational wave generator simulating mergers of compact objects
- A space-time fabric model explaining gravity and gravitational waves
- A gravitational wave activity kit for children
- A Michelson interferometer model to demonstrate how LIGO detects gravitational waves

These models helped demystify complex scientific concepts for a diverse audience and sparked curiosity among young visitors.

(Khagol 136, April 2025)

Ph.D. DEGREES AWARDED

PH. D. PROGRAMME

During the year of this report, fifteen IUCAA Research Scholars, namely: **Bhaskar Arya** [Guide: Aseem Paranjape], **Navin Lalta Prasad Chaurasiya** [Guide: Surhud More], **Partha Pratim Deka** [Guide: Neeraj Gupta], **Suprovo Ghosh** [Guide: Debarati Chatterjee], **Tathagata Ghosh** [Guide: Sukanta Bose (until 26.07.2023) and Gulab Chand Dewangan (since 27.07.2023)], **Amit Kumar** [Guide: Surhud More], **Shrabani Kumar** [Guide: Gulab Chand Dewangan], **Ankush Mandal** [Guide: Dipanjan Mukherjee], **Meenakshi** [Guide: Dipanjan Mukherjee], **Anuj Mishra** [Guide: Gulab Chand Dewangan], **Samanwaya Mukherjee** [Guide: Surhud More], **Bikram Keshari Pradhan** [Guide: Debarati Chatterjee], **Premvijay V.** [Guide: Aseem Paranjape], **Parisee Sunil Shirke** [Guide: Dipanjan Mukherjee], and **Kanchan Soni** [Guide: Sanjit Mitra], have defended their Ph.D. theses. The Jawaharlal Nehru University, New Delhi, has awarded them Ph.D. degrees.

The synopses of their theses are given below:

Bhaskar Arya

Exploring the Nature of Dark Matter using Cosmological and Astrophysical Probes.

Abstract: Dark matter constitutes roughly 83formation at large scales. Despite its abundance, the elusive nature of dark matter forces us to rely upon indirect observations. The observations of Lyman- (Ly) forest have been an important astrophysical probe to study its nature for several decades. The flux statistics of Ly spectra is sensitive to both cosmological parameters and the astrophysical processes of the intergalactic medium (IGM). In this thesis, we aim to assess the performance of the lognormal model, which is a fast semi-numerical tool for simulating the Ly forest, in comparison with full-fledged high-resolution cosmological hydrodynamical simulations. To this end, we have developed an end-to-end MCMC analysis method to constrain astrophysical and cosmological parameters using the lognormal approximation, which models the IGM by assuming the 1-dimensional baryonic number density to be a lognormal field. In this thesis, firstly, we test the validity of lognormal model in recovering astrophysical parameters against high resolution Sherwood simulations at a single redshift, z = 2.5. Secondly, we extend this analysis to other redshifts with improved methodology and track the redshift evolution of thermal and ionization parameters. Lastly, we briefly present results about the effects of cross-redshift correlations on parameter estimates in a combined redshift analysis. Our work can be further extended to constrain cosmological parameters, as well as parameters related to the nature of dark matter.

Navin Lalta Prasad Chaurasiya

Gravitational Lensing: Galaxy-Dark Matter Connection and Cosmology.

Galaxies form and evolve within the gravitational potential of virialized clumps of dark matter called halos. The stellar mass halo mass relation (SHMR) of galaxies represents the integrated outcome of the star formation and feedback processes that result in the formation and evolution of galaxies, and is therefore one of the key observables that various galaxy formation theories attempt to reproduce. The galaxy dark-matter connection

also allows modelling of observables on much smaller scales and is thus important for improving the precision of cosmological constraints. In this thesis, we use weak gravitational lensing and infer the SHMR over two orders of magnitudes in stellar masses and its evolution over nearly a quarter of the age of the Universe, using imaging data from the Subaru Hyper Suprime-Cam (HSC) survey for the first time, fulfilling one of its key science goals. We will present comparisons of the inferred SHMR with results from subhalo abundance matching and halo occupation distribution models that rely on the abundance and clustering of galaxies. We also present a framework to understand how photometric redshifts for galaxies can systematically affect the weak lensing signal and bias the inference of the SHMR. Finally, we present measurements of the weak lensing signals of galaxies from the DESI one-percent survey and test models of galaxy assembly bias deduced from the use of galaxy clustering, counts-in-cylinders and the abundance of galaxies.

Partha Pratim Deka

An unbiased view of cold atomic gas associated with radio loud AGNs.

Cold gas (T 100 K) associated with radio-loud AGNs offers valuable insights into the processes of AGN feeding and feedback at different scales within a galaxy – crucial for understanding galaxy evolution. The 21-cm line from neutral hydrogen (H i) in absorption has been extensively used to study the kinematics and distribution of cold gas associated with radioloud AGNs across various AGN classes and redshifts. However, despite significant efforts, our understanding of these properties has been limited to low-redshift samples (z < 1) that are often preselected based on properties observed at other wavelengths (mainly optical and infrared). As a result, an unbiased investigation into the relationship between cold gas properties and various AGN parameters (such as redshift, radio power, and excitation mode) is still lacking, and a comprehensive understanding of these dependencies is yet to be established. Recognizing the importance of cold gas in galaxy evolution and its role in tracing key processes like AGN feeding and feedback, numerous large-scale surveys are underway, including those involving upcoming Square Kilometre Array (SKA) precursors and pathfinders. Among these, the ongoing MeerKAT Absorption Line Survey (MALS) – data from which have been used in this thesis – is being conducted using the L- (900-1670 MHz) and UHF- (580-1015 MHz) bands of the MeerKAT array. MALS will cover 1000 deg2 of the sky at +20◦ across 400 pointings, each with a field of view of 88 (FWHM) at 1.0 GHz. With its wide bandwidth and relatively RFI-free environment, MALS is carrying out the most sensitive (H i column density, N(H i) > 1019 cm2), dust-unbiased search for cold neutral and molecular gas phases in and around galaxies using the 21-cm line from Hi (0 < zHi < 1.4) and the OH 18-cm line tracing H2 (0 < zOH < 1.8) in absorption as tracers. Utilizing data from 391 MALS L-band pointings (0 < zHi < 0.5) and one from the UHF-band (0.4 < zHi < 1.4), this thesis presents an "unbiased" search for cold gas associated with radio-loud AGNs, i.e., without pre-selecting sources based on radio band properties such as radio size or spectral index. To achieve this, the initial step involves generating a radio continuum catalog that characterizes the properties of radio sources detected across 391 L-band pointings. From this catalog, radio AGNs brighter than a few mJy may be searched for absorption using MALS L-band spectra. The catalog includes 15 narrowband images within the 856 MHz-wide L-band, providing source properties at 15 different frequencies in the 900-1670 MHz range. The final catalog, which combines sources detected in all 15 narrowband images, contains the radio continuum properties of 715,760 sources detected with a signal-to-noise ratio (SNR) > 5. To characterize the continuum catalogs, we used properties of 240,321 sources detected at 1.4 GHz images with a spatial resolution of 8. We assessed the accuracy of MALS source positions and flux densities by comparing them with literature surveys at similar frequencies (i.e., 1.4 GHz), specifically the NRAO Very Large

Array (VLA) Sky Survey (NVSS) and the Faint Images of the Radio Sky at Twenty Centimeters (FIRST). This comparison established the catalog's accuracy in the flux density scale and astrometry to be better than 6which has been used in this data release for correcting the images for the primary beam response of MeerKAT, we also analyzed the catalog properties for an alternate primary beam model that is based on holographic measurements. In this case, the median flux density offset with NVSS was found to be higher (9found them in agreement with the literature. From spectral index () measurements of 125,621 sources (SNR>8), we confirmed the flattening of spectral indices with decreasing flux density, and also identified 140 ultra steep-spectrum (< 1.3) sources as prospective high-z (z > 2) radio galaxies. The catalogs and images are publicly available at https://mals.iucaa.in. In the next step, we utilized SDSS DR18 spectra of MALS-detected sources to create a sample of low- and high-excitation radio galaxies (LERGs/HERGs). This sample includes sources brighter than 1 mJy at 1.0 GHz and at redshifts z < 0.5. We present the detailed stages of classification, including optical emission line measurements, classification into AGN and star-forming galaxies, and the methodology adopted to classify the radio-loud AGNs into LERGs and HERGs. The final sample consists of 352 sources (248 LERGs and 104 HERGs). Among 110 RFI-free sources with flux densities 2 mJy near the 21-cm line frequency, we detected Hi 21-cm absorption in 12 new systems (6 HERGs and 6 LERGs). This yields detection rates of 19.4+11.6 7.7 per cent for HERGs and 7.6+4.5 3.0 per cent for LERGs, consistent with HERGs being associated with optically bluer and actively star-forming galaxies. We also found that the majority (>90exhibit compact radio morphology and WISE mid-infrared (MIR) color W2W3 2, indicating gas-rich systems. Additionally, we observed differences in the kinematic properties of cold gas between LERGs and HERGs. LERGs displayed wider and more asymmetric absorption lines, with a greater blueshift or redshift of the absorption peak relative to the host galaxy's optical redshift. These results align with findings from the literature in samples of brighter (> 30 mJy at 1.4 GHz) and nearby (z < 0.25) AGNs. Finally, we used UHF-band data to report the discovery of Hi 21-cm absorption in a high-z (zem 1.35), powerful (1.4 GHz luminosity, L1.4GHz = 1027.2WHz1) quasar: J2339-5523. The detected absorption profile is broad (400 kms1), and the peak is redshifted by 200 kms1 from zem . In addition to being a rare detection, the case of J2339-5523 appears to be intriguing because it lacks metal absorption signatures in its optical (3330–9300 A) and FUV (1100–1800 A) spectra obtained using Magellan-MIKE and HST-COS spectrographs, respectively. This is despite the coincident presence of the optical quasar and the radio 'core' with a flux density of 65 mJy, inferred from high frequency (> 5 GHz) observations from the AT20G survey. The simplest explanation would be that no large Hi column (N(H i) > 1017 cm2) is present towards the radio 'core' and the optical AGN. In order to understand the location of the absorbing clouds, we compared the optical and radio properties of literature samples of 16 quasars and 19 radio galaxies with Hi 21-cm absorption detections, matched in L1.4GHz. The analysis revealed that quasars trace gas in the inner circumnuclear disk and cocoon created by the jet-ISM interaction. These exhibit correlation between L1.4GHz and the velocity width of the absorption profile (Vnull), with frequent mismatches between radio and optical spectral lines. Radio galaxies, however, do not show this correlation and likely trace gas from the cocoon and galaxy-wide ISM outside the photoionization cone. This analysis highlights the potential of radio spectroscopic observations to reveal the origin of the absorbing gas associated with AGN that may be missed in optical observations.

Suprovo Ghosh

Constraining Neutron Star Equation of State using Multi-disciplinary Physics and its application in studying various aspects of Gravitational Wave emission.

Neutron stars (NS) are one of the densest astrophysical objects in our Universe, born at the end-point of the stellar evolution of massive stars following a core-collapse supernova. In the NS interior, the density of matter can reach several times of nuclear saturation density. At such high density, nuclear matter is beyond the reach of current terrestrial experiments. So, one must resort to theoretical models to describe the behavior of nuclear matter at such high density inside NS cores. A crucial entity required for calculating the NS observables is the pressure-energy density relationship for neutron star matter, also known as the Equation of State (EOS). One of the key goals of studying neutron stars is to use astrophysical observations to infer the neutron star EOS and the interior composition of neutron stars. Following the detection of gravitational waves from the neutron star merger event GW170817 by the Laser Interferometer Gravitational-Wave Observatory (LIGO) and Virgo detectors, there have been many attempts to impose constraints on the EOS by combining these multi-messenger observations of neutron stars using a statistical Bayesian scheme. Most of these works have focused on constraining the high-density part of the EOS based on different parametrization schemes such as piecewise polytropes, spectral representation, speed-of-sound parametrization, or non-parametric EOSs from Gaussian process. However, such inferences lack an understanding of the role of the underlying nuclear physics, such as the key nuclear saturation parameters that control the behavior of NS global observables. One of the primary goals of this thesis was to constrain the nuclear EOS applying state-of-the-art data from multiple experimental and astrophysical channels at different densities. We imposed constraints on the parameter space of both nucleonic and hyperonic EOSs in the Relativistic Mean Field (RMF) model applying a cut-off filter scheme with statistical weights, using for the first time information from multi-disciplinary physics at different density regimes: theoretical Chiral Effective Field Theory (EFT) at low densities, multi-messenger (multi-wavelength electromagnetic as well as GW) astrophysical data at high densities, and experimental nuclear and heavy-ion collision data at intermediate densities. This approach allowed us to systematically explore possible correlations among nuclear empirical parameters and astrophysical observables. Until now, only from direct detections of binary neutron star mergers, the tidal deformability and masses of the component neutron stars have been measured, which imposed important constraints on the dense matter EOS. But there are still other possible gravitational wave observables from binary NS mergers or even isolated neutron stars that are expected to be within the observable LIGO sensitivity band but yet to be detected. One such promising aspect is from normal mode oscillations in neutron stars. Particularly interesting are the axial r-modes, which are analogous to Rossby waves in Earth's oceans. They are unstable in all rotating neutron stars due to the Chandrasekhar-Friedman-Schutz (CFS) mechanism and, are promising candidates for Continuous Gravitational Wave observations. In this thesis, we have explored how the frequency of the r-modes depends on the internal structure of the star, and how we can determine various NS observables following a successful detection from targeted searches. We also explored how the gmode frequencies (restored by buoyancy) could be a possible resolution to breaking degeneracies in inferences on the EOS from M-R data alone, and ascertain if hyperons (strange baryons) exist in the NS interior. Along with the EOS, which relates the equilibrium pressure with the density, knowledge of transport properties such as the viscosity of dense matter inside NS and their dependence on the composition, is crucial for understanding NS structure and their evolution. Viscous processes inside the neutron star can dampen the mode-oscillations and also tidal energy during inspiral. In this thesis, we developed a novel approach to probe dark matter inside neutron stars using r-modes. We also demonstrated for the first time that tidal heating during the inspiral phase of a binary NS merger could provide a smoking-gun signature for presence of hyperons inside neutron stars. We anticipate that with the ongoing GW observations using the global network

of LIGOVirgo- KAGRA (LVK) detectors and also, with upcoming third-generation detectors like Einstein Telescope (ET), Cosmic Explorer (CE) or Neutron Star Extreme Matter Observatory (NEMO) we will observe more GW events from both isolated and binary NS mergers and be able to constrain further the dense matter EOS in the near future using the various aspects of these GW observations that we explored in this thesis.

Tathagata Ghosh

Measuring Cosmological Parameters with Gravitational-Wave Observations.

The discovery of gravitational waves (GWs) from compact binary coalescences (CBCs), such as binary black holes (BBHs) and binary neutron stars (BNSs), has opened a new window to study the expansion rate of the Universe, encapsulated by the parameter called the Hubble constant (H0). GWs provide a unique probe to directly estimate the luminosity distances of binary mergers, but not their redshifts. The redshift is obtained, for example, from electromagnetic (EM) counterparts, as is sometimes the case with BNSs. BBH mergers, however, are not expected to be accompanied by EM radiation and a subsequent determination of their redshift. Additionally, even for BNS mergers, detecting EM counterparts is not always feasible. Therefore, independent redshift measurements for such GW events devoid of EM information, referred to as dark sirens, are essential for measuring H0. The current state-of-the-art methods, as adopted in the recent LIGO-Virgo- KAGRA cosmology analysis, to estimate the Hubble constant from BBHs, do not explicitly account for the spatial clustering information of galaxies. The primary focus of the thesis is to develop two Bayesian formalisms to estimate the Hubble constant from dark sirens: (a) BBHs, which are not expected to have EM counterparts, and (b) BNSs without accompanying EM counterparts. First, we present a Bayesian approach to infer the Hubble constant from the cross-correlation between galaxies with known redshifts and individual BBH events, utilizing largescale structure information that has not previously been used when statistically identifying the hosts of GW events. While most GW events detected so far have been BBH mergers, GW detectors also detect binary neutron stars, although fewer in number and with only a single event observed with an EM counterpart. For dark BNSs without EM counterparts, the tidal deformations of BNS components offer insights into the neutron star (NS) equation of state (EoS). In such cases, the tidal parameters of NSs, combined with knowledge of the NS EoS and assuming a relationship between mass and tidal deformability, can break the degeneracy between mass parameters and redshift, allowing for the inference of the Hubble constant. Additionally, this thesis presents another Bayesian analysis that jointly constrains the NS EoS, population, and cosmological parameters using a population of dark BNSs detected through GW observations. This method can estimate the Hubble constant not only from BNSs detected by next-generation detectors but also with as few as 5 BNS events using the current-generation detectors. Furthermore, this thesis introduces a novel 2 statistic for efficient identification of CBC signals against blip glitches - short-duration noise transients present in the LIGO detectors that severely impact GW search sensitivity. The methods and results presented in this thesis contribute to the broader effort of using GW observations for precision cosmology, offering new tools to extract valuable information from dark sirens and improving the overall sensitivity of GW searches.

Amit Kumar

Gravitational lensing in galaxy clusters.

How do satellite galaxies evolve in dense environments and what differentiates them from galaxies evolving in isolation in the field, is one of the key questions in galaxy evolution. For central galaxies, the mass of a galaxy is the primary property that correlates with its properties and drives its evolution. Therefore, comparing the matter distribution around satellite galaxies with that around similar galaxies evolving isolated in the field can shed light on the environmental nurture of satellite galaxies and its effect on their evolution. Gravitational lensing gives direct measurements of the mass distribution around galaxies without recourse to assumptions of hydrostatic equilibrium, or stellar velocity dispersion anisotropies. In this thesis, we use the weak lensing catalogs from the Subaru Hyper Suprime-Cam survey a) to infer the (sub)halo masses of satellites and compare them to those of a control sample of field galaxies, b) to determine the effect of dense environment in the galaxy clusters on the evolution of these subhalo masses, c) to establish the connection between subhalo masses for satellites with their observable galaxy properties such as their luminosity and stellar mass, in addition to its dependence on the richness of the host cluster (number of satellite galaxies), and d) for the first time, to put a robust observational upper limit on the population of galaxies that have lost all of their dark mass. We assess predictions of a leading empirical model of galaxy formation and evolution in simulations with these inferences. We discuss what these models get right and areas that need improvement.

Shrabani Kumar

AstroSat view of accretion discs in Active Galactic Nuclei.

Active Galactic Nuclei (AGN) are among the most luminous and persistent objects in the universe. Their emission span almost the entire band of the electromagnetic waves, from radio to rays. The bolometric luminosity of such objects is in the range of 1041 1048 erg s1. Such a tremendous luminosity from the compact nuclear region is believed to arise from the accretion of matter onto a central supermassive black hole (MBH 105 1010 M). The major emission components in the spectral energy distribution (SED) of radioquiet AGN are the big blue bump (BBB; 1000A to 1m), the infra-red bump, the primary X-ray continuum (cutoff at 100 keV), and the X-ray reflection (Compton hump 20 50 keV and iron emission lines around 6 – 7 keV). There is another emission component observed below 2 keV over the powerlaw, known as the soft X-ray excess. The SED is not fully understood in terms of the geometry of the emitting regions, the physical processes responsible for the emission components, and the connection between different emission components. The BBB is thought to arise due to the accretion of matter onto a supermassive black hole. Shakura Sunyaev (1973) proposed a standard accretion disk model and predicted that the emission from the accretion disk follows a power law (f 1/3). However, the shape of the spectrum from standard disks may get altered due to contamination from the host galaxy, emission lines from the broad and narrow line regions (BLR and NLR), Fe II complex, Balmer continuum, and extinction due to the host galaxy and our own Galaxy. In this thesis, we derive the intrinsic far and near UV emission from Seyfert

1 galaxies after implementing all possible corrections to the observed spectra. We test the standard accretion disk model against the intrinsic UV continuum. The X-ray power-law continuum is thought to be originating from the innermost regions, referred to as the corona. The low energy photons arising from the accretion disk get repeated Compton up-scattered into the high energy photons (X-rays) in the hot (kTe 100 300 keV), optically thin (1) corona. This physical process is referred to as thermal Comptonization. A fraction of the X-ray power law emission illuminates the disk. These X-ray photons interact with the disk material and produce several fluorescent emission lines via photoelectric absorption and a Compton hump via Compton down-scattering. In the soft X-ray band (below 2 keV), an excess over the power-law emission is observed (kT 0.11 keV) in many Seyfert 1 galaxies. The nature and the origin of this soft X-ray excess emission remain poorly understood. One of the models, referred to as the blurred reflection, assumes that the soft X-ray excess component is a part of the X-ray reflection from a partially ionized accretion disk. In this case, the relativistic Doppler broadening of the emission lines and scattering of the photons in the soft X-ray band give rise to a smooth continuum component, similar to the observed soft excess, above the broadband power-law X-ray continuum. Another competing model referred to as warm Comptonization, treats the soft X-ray excess as a separate component originating near the inner disk. The seed photons from the standard disk get Compton up-scattered in a warm (kT 0.1 1 keV) optically thick (10 40) corona. In light of the warm Comptonization model, I investigated the spectral connection between the soft X-ray excess and the disk emission in type 1 AGN. Further, using the near/far UV to X-ray spectra, I study the accretion disk, soft excess, and power-law components and try to constrain the black hole spin in a 'bare' Seyfert 1 galaxy Fairall 9 using the continuum fitting method. Finally, utilizing all the co-aligned science instruments onboard AstroSat, I explored the UV extinction and the X-ray absorption in an intermediate Seyfert galaxy NGC 4151. I utilized the data acquired with AstroSat, HST, and XMM-Newton space observatories in our UV/X-ray spectral analyses. In this thesis, I focus on (a) deriving the intrinsic disk emission and testing the standard accretion disk model, (b) investigating the UV – X-ray spectral shape and connection between the different spectral components, and (c) exploring the possibility of black hole spin measurement using UV – X-ray spectral modeling. The thesis begins with an introductory chapter describing the discovery, classification, broadband SED of AGN, and the underlying physical processes of the various emission components. This chapter also deals with the motivation and organization of the thesis. Chapter 2 describes the space missions and the data used in this thesis. This is followed by the data analysis techniques and the models we implemented and used in the spectral modeling. In the following chapters, 3, 4, 5, and 6, I describe the work done in this thesis. In Chapter 7, I summarize the results. In Chapter 3, we investigate the accretion disk emission in eight Seyfert 1 galaxies: Mrk 841, MR 2251– 178, PG 0804+761 (hereafter PG0804), NGC 7469, I Zw 1, SWIFT J1921.1–5842 (hereafter SWIFT1921), Mrk 352, and SWIFT J1835.0+3240 (hereafter SWIFT1835). We utilized the grating spectra acquired with the Ultra-Violet Imaging Telescope (UVIT) onboard AstroSat, and the Cosmic Origin Spectrograph (COS) and Faint Object Spectrograph (FOS) onboard HST. The spatial resolution of 1 1.5 in the UVIT filters allows us to estimate the flux contribution of the host galaxy to the AGN emission. We used the radial surface brightness profile to decompose the host galaxy contribution from the AGN emission. We found < 3galaxy contribution to the AGN in our sources. The UV/optical emission is subjected to extinction due to both the host galaxy and our own Galaxy. We used the extinction curve of Cardelli et al. (1989) to account for the Galactic reddening. Internal reddening is one of the major uncertainties in determining the intrinsic disk emission. We used the extinction curve provided by Czerny et al. (2004) to account for the internal extinction in our sources. We created a model to implement this extinction curve during the spectral modeling in Sherpa or XSPEC packages. We used the high-resolution spectral data acquired with the HST to estimate the intrinsic reddening, as the poor spectral resolution of the UVIT/grating spectra does not allow us to do so. We also developed spectral models to account for Fe II complex (11005500A) and Balmer continuum emission (2000 4000A) originating from the BLR. We derived the intrinsic continuum for the HST and UVIT grating spectra after accounting for Galactic and intrinsic extinction, Fe II emission, Balmer continuum, and emission lines from the BLR and NLR. We found that the spectral index (for the UVIT/gratings observations) ranges between 1.1 to 0.3 (as in F). We found the UV continua consistent with the standard accretion disk spectrum. The peak disk temperatures are generally lower than predicted for

an accretion disk around a Kerr black hole accreting at the Eddington accretion rate. The accretion disk of NGC 7469 and Mrk 352 appears to be truncated at 35 125 rg and 50 135 rg. In Chapter 4, we extended our work presented in Chapter 3. We performed broadband UV/X-ray spectral analysis of four AGN: NGC 7469, PG0804, SWIFT1921, and SWIFT1835. The broadband UV – X-ray spectral modeling revealed that three sources (except for SWIFT1835) are accreting at 50The only radio-loud source in our sample, SWIFT1835 has the lowest Eddington ratio (0.02). We found three sources exhibit a truncated disk at a radius more than 10rg. In the case of NGC 7469, by comparing with the previous observations by Mehdipour et al. (2018), we found that the UV and soft X-ray fluxes are correlated while the hard X-ray flux seems uncorrelated. This might indicate that the origin of soft X-ray excess could be the warm Comptonization. Our broadband UV/X-ray spectral data favor a low spin for NGC 7469. In the case of PG0804, we have a broader wavelength coverage in the UV waveband (1300 – 3100 A). We found the AGNSED model describes our broadband UV/X-ray data better than the OPTXAGNF model. In other words, the outer accretion disk emits like a multi-temperature blackbody rather than a modified blackbody. We could also constrain the spin parameter in this source, a = 0.83+0.07 0.21. For SWIFT1921, the source fluxes in all three spectral components (disk, soft X-ray excess, and the hard X-ray emission) are twice as high as those reported in previous observations by Gondoin et al. (2003) and Ghosh Laha (2020). We found a steeper photon index (2) compared to that obtained by Gondoin et al. (2003) (1.72). This supports the thermal Comptonization of the disk photons in the hot corona, typically observed in AGN. The only radio-loud object in our sample, SWIFT1835, has the hardest photon index (1.56). We found the peak effective disk temperature kTin < 1.4 eV. Additionally, from the five observations performed in 2016 with XMM-Newton (UV and X-ray data), Ursini et al. (2018) found the photon index 1.78, and the disk temperature kTin 3.4 eV. The reduction in the disk temperature and a harder photon index during our observation suggests thermal Comptonization of disk photons being responsible for the spectral variability in this source. This is consistent with the findings of Ballantyne et al. (2014), who found that the bright X-ray state of SWIFT1835 exhibits lower coronal temperature than the dim X-ray state. In Chapter 5, we study the broadband near and far UV to X-ray (0.0047 keV) SED of a bare AGN Fairall 9 using the AstroSat observation performed in 2016. We observed a redder UV spectrum (0.68 as in F) than predicted from the standard accretion disk model. We investigated the broadband SED for two accretion flow geometries. In one case (the OPTXAGNF model), the disk is truncated at a radius rcor. The outer disk emits like a modified blackbody beyond rcor. While, the disk seed photons at rcor produce the soft X-ray excess and the X-ray power-law emission below rcor. In the other case (AGNSED model), the accretion flow has three regions: an outer standard disk, a warm Comptonization region above a passive disk, and an inner hot flow forming the corona. We found the latter model better describes our broadband UV/X-ray spectral data than the former. Further, we could constrain the black hole spin parameter. With the AGNSED model, we found the spin parameter to be 0.87+0.04 0.07, while the OPTXAGNF predicted a moderate spin parameter 0.49+0.04 0.15 in this source. The discrepancy in the spin estimations may have occurred due to the differences in the energetics associated with the emitting regions, leading to varying bolometric luminosities between these models. In Chapter 6, we explore the near ultraviolet (NUV) to hard X-ray (0.005 80 keV) spectral variability of the brightest hard X-ray radio-quiet AGN NGC 4151 using five sets of multi-wavelength observations performed with AstroSat during 2017 – 2018. We utilized the data acquired with all the co-aligned payloads – the UVIT, SXT (Soft X-ray Telescope), LAXPC (Large Area X-ray Proportional Counter), and CZTI (Cadmium-Zinc-Telluride-Imager) onboard AstroSat. The X-ray spectral modeling revealed a large X-ray absorption column density (NH 1023 cm2) along the line of sight. We investigate whether this large obscuring column is also obscuring the UV emission from NGC 4151. We estimate the intrinsic extinction using a high-resolution UV spectrum acquired with HST/STIS (Space telescope imaging spectrograph) during one of the low UV/optical flux states (2000 March) of NGC 4151. The spectrum from this particular HST observation is similar to one of our UVIT/FUV grating observations. We obtained the extinction, E(B-V) 0.38. We used this value for all five UVIT spectral analyses. We modeled our broadband UV/X-ray spectra with the intrinsic and Galactic extinction, thermal Comptonized disk emission, distant X-ray reflection, neutral and ionized X-ray absorption, and soft X-ray excess emission. The peak effective disk temperature varied between 8.7 to 10.3 eV between the observations. The UV color (FUV–NUV) is observed to decrease with the rise

in the FUV or NUV flux. This anti-correlation between the UV color and the observed flux may have been caused by both the variation in the intrinsic extinction and intrinsic shape of the spectrum ('bluer when brighter' trend). We found the X-ray absorbing column density increases with the rise in the observed UV flux. The increasing UV flux may have resulted in stronger winds, leading to stronger X-ray absorption. We found the NH inferred from the UV extinction, assuming a Galactic dust-to-gas ratio, is 100 times smaller than that the X-ray absorption column density. This suggests that the dust-to-gas ratio in the environment of NGC 4151 could be way smaller than the Milky Way. We invoke two possible scenarios to reconcile this discrepancy assuming the same obscurer is eclipsing both the UV and the X-ray source. In one scenario, the obscurer could be a two-phase medium with dense compact clouds embedded in a low-density medium. The X-ray emitting source (corona), being compact, could be completely obscured by the compact dense clouds, while a bulk of the UV emission originating from an extended accretion disk may pass through the low-density medium. In addition, the moving high-density compact clouds may also lead to the X-ray NH variability. In another scenario, the obscurer could have two zones divided by the dust sublimation radius. The dust and grains beyond the sublimation radius are predominantly responsible for the UV reddening, while the gas and dust both inside and outside the sublimation radius could account for the X-ray absorption. In either of these scenarios, the X-ray absorbing column could be substantially larger than the column density inferred from the UV extinction.

Ankush Mandal

Modelling the Impact of AGN driven Outflows on the Star Formation Activity in Galaxies.

The central supermassive black holes (SMBHs) in galaxies play a pivotal role in shaping the evolution of both their host galaxies and the surrounding medium. These black holes are far from being mere cosmic ornaments; rather, they are significant drivers of galactic evolution due to the immense energy they release during the accretion process. This energy can profoundly influence various physical processes within galaxies. For instance, the large-scale outflows from active galactic nuclei (AGN), often manifesting as powerful jets, heat the intracluster medium and effectively curtail the cooling flows that would otherwise bring material towards the centre of the galaxy cluster. This mechanism helps regulate the stellar mass growth by preventing excessive accumulation of cold gas. Conversely, the local energy input from winds and young jets into the interstellar medium (ISM) of the host galaxy can significantly alter the physical state of the gas. This interaction can impact the dynamics and the star formation processes within the galaxy. Star formation is inherently complex and sensitive to the local turbulent properties of the star-forming gas, necessitating sophisticated modelling in numerical simulations to accurately capture these effects. To address these challenges, we have developed an advanced subgrid model for turbulence-regulated star formation that improves upon previous models that relied primarily on simple density thresholds. This development also led to the creation of two state-of-the-art general-purpose modules for self-gravitational hydrodynamics and "sink particles" within the PLUTO code, allowing for more accurate in-situ modelling of star formation. By applying these new modules to galactic-scale simulations of jet-disk interactions, as well as to resolved simulations of interactions between outflows and individual star-forming clouds, we gain insights into the complex effects of AGN-driven outflows on star formation. Our findings reveal that the impact of AGN feedback on star formation is multifaceted and often governed by competing mechanisms. On a global scale, the energy and momentum imparted by AGN outflows can heat the gas and induce significant turbulence, leading to a reduction in the star formation rate (negative feedback). This outcome occurs even in the presence of dense gas, demonstrating that AGN feedback can suppress star formation without necessarily expelling significant

amounts of starforming material from the galaxy's gravitational potential. This result aligns with several observational studies highlighting the reduction in star formation rates due to AGN feedback. Simultaneously, radiative shocks associated with AGN activity can locally compress the gas to very high densities, increasing the likelihood of gravitational collapse and thus enhancing the star formation rate (positive feedback). Our research shows that this dichotomy between negative and positive feedback is far from straightforward. A single system can experience both types of feedback simultaneously, depending on factors such as scale, location, and the strength of the interaction between the ISM and AGN-driven outflows. This complexity underscores the need for detailed, multifaceted approaches to understanding the interplay between AGN feedback and star formation.

Meenakshi

Simulating effects of AGN-driven outflows on galactic scales and predicting their observable signatures.

Recent observational advances have shown that active galactic nuclei (AGN)-driven jets and winds are ubiquitous in massive galaxies. However, how these two couple with the host's interstellar medium (ISM) is still not clearly understood. Nonetheless, in young and compact sources, determining the exact mechanism of radio emission is often challenging. This thesis focuses on a comprehensive analysis of AGN-driven jets and winds, attempting to address the above issues and establish a link between simulations and observations. The content of the thesis is as follows. Firstly, we utilize results from resolved simulations of jet-ISM interactions within the central few kiloparsecs of the host system to investigate the impact of AGN on gas ionization. Our analysis includes examining the ionization extent from AGN radiation and jet with kinetic power comparable to AGN's bolometric luminosity. Additionally, we explore the shocked thermal emission and the kinematics of shocked gas in systems influenced by jets. The key findings of these studies include: (i) Thermal energy injected by the jet can shock-ionize the dense gas extensively. Jets inclined towards the disc plane couple more strongly with the ISM and ionize a larger fraction of gas in the disc when compared to the vertical jet. The jets also clear out the central regions of the host galaxy, allowing the radiation to progress further. However, the self-shielding by the outer layers of the dense clumps blocks the AGN ionizing radiation and prevents it from affecting the inner regions. (ii) Jet-induced laterally expanding forward shock of the energy bubble sweeping through the ISM causes large-scale outflows, creating shocked emission and high-velocity dispersion in the entire nuclear region of the host. These jets impact not only their immediate surroundings but can disturb the kinematics in regions far from their axis. However, after the jets escape their initial confinement, the jet-ISM coupling weakens, and gas in the system begins to settle and cool down in the presence of the host's gravitational potential, resulting in lower shocked emission and velocity widths. Using RMHD simulations, we have also studied the evolution of collimated relativistic jets and wideangled mildly-relativistic winds in turbulent magnetic fields. Furthermore, the evolution of non-thermal particles (cosmic ray electrons or CREs) and their effect on their radio spectra in both scenarios is also explored. These are the findings from these studies: (i) The turbulent field in the ambient medium is compressed and amplified by the jets and winds as they progress, which leads to high polarization at the forward shock with fields aligned along the shock surface. The randomness in the magnetic polarities of the fields in the shocked ambient medium (SAM) results in lower polarization values than those obtained from the jet's and wind's cocoon only. It is found that due to the slow decay of the fields in the SAM, such depolarization by the fields with large correlation lengths is more prominent when compared to the smallscale fields. Also, the low-power jets/winds, which have magnetic fields comparable in strength to those in the SAM, are more severely affected by the SAM's depolarizing effect, than the high-power ones. (ii) Collimated jets and wide-angled winds are found to exhibit different dynamic evolutions,

leading to variations in their non-thermal emission and polarization characteristics. Jets exhibit compact, bright emissions from narrow spines and hotspots, with high polarization values. Winds show widespread features, with a polarized broad column capped with polarized bright arcs. Both jets and winds in our studies are launched with toroidal magnetic fields, and it is observed that the jet's cocoon has a more significant strengthening of the poloidal component. This is attributed to the shearing of magnetic fields and powerful backflows, which are more pronounced in jets compared to winds. We also demonstrate that the emission features from both jets and light unstable winds can become indistinguishable at lower resolutions, emphasizing the high-resolution observations. However, the distribution of polarization remains largely unaffected, though lower polarization becomes more noticeable when the resolution is decreased. (iii) From our study on the evolution of CREs in jets and winds, it is found that in the jets, particles undergo several shock crossings along the spine until they reach the hotspot and then move back with the backflow. In contrast, in winds, most particles pass through the shock at the Mach disc. This difference significantly impacts the multi-frequency synchrotron emission and spatial variation of radio spectra from jets and winds. Specifically, in jets, we observe flatter spectral indices near the hotspot, while steeper indices are found in the lobes. Conversely, in winds, the radio spectra become steeper as one moves away from the Mach disc, which is more prominently seen at higher frequencies. In summary, this thesis presents a detailed investigation into the interaction between AGN-driven outflows and the ISM of their host galaxies. Through a combination of simulations, we also elucidate the differences in synchrotron emission from jets and winds. The final chapter discusses the findings and potential future prospects of this thesis work.

Anuj Mishra

Exploring Wave Effects in the Lensing of Gravitational Waves from Chirping Binaries.

With increasing sensitivities of current ground-based gravitational wave (GW) detectors, the prospects of detecting gravitationally lensed GW signals are poised to improve in the coming years. While the lensing of GWs shares similarities with electromagnetic waves, their observed effects can exhibit striking differences. This thesis delves into the impact of wave-optics effects in gravitational lensing of GWs originating from compact binary coalescence.

When a GW encounters compact objects, such as stars, stellar remnants, or possible compact dark matter objects like primordial black holes, it can lead to the emergence of wave-optics effects. These effects result in frequency-dependent modulations of the signal, which we refer to as 'microlensing.' In such cases, the geometrical optics approximation breaks down, necessitating the consideration of the wave nature of propagation. Consequently, these frequency-dependent modulations influence the GW strain, potentially introducing biases if these lensing effects are not accounted for. This leads to natural questions: When do these modulations become significant? What parameters can they affect? How do these microlenses behave when embedded in a strong lens, such as lensing galaxies? Can they influence other GW analyses, such as tests of general relativity (GR)? What are the prospects for their detection and their population characteristics? Additionally, is there degeneracy with other physical effects, such as eccentricity?

In this thesis, I aim to answer these questions, with some of them being investigated for the first time in the literature. I begin by demonstrating how microlensed signals affect the detectability of GW signals from the perspective of standard matched-filter searches. I find that while typical unlensed searches can significantly decrease the true signal-to-noise ratio (SNR) by over 30%, the presence of isolated microlenses consistently amplifies the GW signals they lens, thereby extending the detection horizon to potentially distant sources, reaching

as far as redshifts $z \sim 10$. I also discuss the consequences of neglecting microlensing effects when inferring source properties. The phase modulations can significantly bias intrinsic parameters, with in-plane spin components (precession) being the most affected. Similarly, amplitude modulations often lead to the underestimation of luminosity distance, by up to a factor of 10 in extreme cases. Study of a population of microlensed signals due to an isolated point lens primarily reveals: (i) using unlensed templates during the search causes fractional loss (20% to 30%) of potentially identifiable microlensed signals; (ii) Bayes factor analysis of the population indicates that certain region in $M_{\rm Lz} - y$ parameter space have a higher probability of being detected and accurately identified as microlensed. Importantly, the microlens parameters for the most compelling candidate in the third GW transient catalogue (GWTC-3), GW200208_130117, fall within a 1-sigma range of the aforementioned high-probability region, favouring the microlensing hypothesis. Furthermore, I explore more realistic scenarios involving microlensing, where a microlens or a population of stellar-mass microlenses is embedded in a strong gravitational lens. I demonstrate how the presence of a strong lens can amplify microlensing effects, effectively increasing the effective mass of microlenses. Consequently, I examine the impact of the microlens population within lensing galaxies on strongly lensed GWs. I find that microlensing atop strong lensing can lead to substantial biases as the strong lensing magnification (μ) increases, with mismatch values exceeding 5% for $|\mu| > 100$. Furthermore, the presence of these microlensing features can also influence strong lensing searches, potentially resulting in orders of magnitude drops in Bayes factors, measuring the strength of the strong lensing hypothesis versus the unlensed hypothesis, especially in extreme cases. Additionally, I investigate how microlensing effects can bias tests of GR, with a confidence level even exceeding 5σ. I show how deviations from GR correlate with pronounced interference effects and also discuss how one can identify such biases to avoid (erroneous) claims of deviations from GR.

Lastly, I discuss how microlensing searches can be biased due to the presence of other atypical physical effects, specifically, the presence of non-zero eccentricity in the signal. I demonstrate the bias in microlensing searches and show that it monotonically increases with increasing eccentricity, the duration of the signal (low mass binaries), and the SNR of the signal. Furthermore, I demonstrate that the degeneracy between microlensing and eccentricity can be broken, and the biases in microlensing searches can be resolved by including eccentricity in the recovery process while doing parameter estimation.

Samanwaya Mukherjee

Characterizing the Properties and Constitution of Compact Objects in Gravitational-Wave Binaries.

Astrophysical observations point toward strong evidence for the existence of black holes (BHs). Nevertheless, it is yet to be established or ruled out with confidence whether some exotic compact objects (ECOs), capable of mimicking black holes from an observational point of view, are indeed doing so. In classical General Relativity (GR), a horizon is the defining feature of a black hole, which prevents any event inside from causally affecting the outside Universe. The quest for distinguishing black holes from horizonless compact objects using gravitational wave (GW) signals from compact binary coalescences (CBCs) can be helped by utilizing the phenomenon of tidal heating (TH), which leaves its imprint on the binary waveforms through the horizon parameters. First, we study the measurabilities of these parameters within the inspiral regime [1]. Then, to extend our investigation for heavier binaries, we construct an inspiral-merger-ringdown waveform by using post-Newtonian calculations for the inspiral and numerical relativity data for the merger-ringdown part that incorporates the effects of tidal heating of black holes in the phase and the amplitude. The new model shows improvements in waveform accuracy when

compared to numerical relativity data [2]. In the late inspiral phase when the compact objects are closer to each other, the effects of tidal heating are stronger, opening up the possibility of identifying the objects more precisely. We demonstrate, from numerical relativity data of binary black holes, how one can model tidal heating in the late inspiral regime and leverage this knowledge to test for horizonless compact objects mimicking black holes [3]. These studies bear significance in determining the nature of compact objects having masses in the entire range that LIGO and future ground-based gravitational-wave detectors can detect. Below, we briefly describe the content and findings in each chapter of the thesis. Chapter 1: Introduction In this introductory chapter we discuss the importance of being equipped with possible tests to tell apart BHs from ECOs that can mimic them in observations. We particularly focus on the fact that GW observations can put constraints on the properties of the compact objects that take part in CBCs, and allow us to design tests to identify their nature. We briefly summarize the properties of Schwarzschild black holes (SBHs) and Kerr blck hole (KBHs) that are relevant to this thesis, and comment on the possible deviations one can detect for ECOs. In the next section, we briefly discuss some of the BH mimicker ECOs that have been hypothesized to exist in the Universe. Chapter 2: Unmasking the Black-hole Mimickers This chapter focuses on the various ways GW observations can distinguish BHs by the presence of their horizons. These tests include the spectrum of quasinormal modes (QNMs), echoes, spin-induced multipole moments, tidal Love numbers, and tidal heating (TH). TH being the BH discriminator that we study in this thesis, we discuss the usefulness of this effect in this role. Chapter 3: Horizon parameters in Post-Newtonian Waveforms In this chapter we investigate the measurabilities of the horizon parameters within the inspiral regime of a compact binary coalescence. These parameters, defined as H1 and H2 with H1,2 [0, 1] for the two compact objects, are combined with the binary components' masses and spins to form two new parameters, Heff5 and Heff8, to minimize their covariances in parameter estimation studies. In this work, we investigate the effects of tidal heating on gravitational waves to probe the observability of these effective parameters. We use a post-Newtonian (PN) waveform that includes the phase contribution due to tidal heating as a function of Heff5 and Heff8, and examine their 1- measurement errors as well as the covariances between them mainly using the Fisher matrix approach. Since this approach works well for high signalto- noise ratios, we focus primarily on the third generation (3G) gravitational wave detectors Einstein Telescope and Cosmic Explorer and use the second generation (2G) detector-network of LIGO (Hanford, Livingston) and Virgo for comparison. We study how the errors vary with the binaries' total mass, mass-ratio, luminosity distance, and component spins. We find that the regions in the total binary mass where measurements of Heff5 and Heff8 are most precise are 2030M for LIGOVirgo and 5080M for 3G detectors. Higher component spins allow more precise measurements of Heff5 and Heff8. For a binary situated at 200 Mpc with component masses 12M and 18M, equal spins 1 = 2 = 0.8, and Heff5 = 0.6, Heff8 = 12, the 1- errors in these two parameters are 0.01 and 0.04, respectively, in 3G detectors. These estimates suggest that precise measurements of the horizon parameters are possible in third-generation detectors, making tidal heating a potential tool to identify the presence or absence of horizons in coalescing compact binaries. We substantiate our results from Fisher studies with a set of Bayesian simulations. Chapter 4: Phenomenological Waveforms for Binary Black Holes incorporating Horizon Fluxes For BHs, the changes in the mass and spin due to TH are associated with their absorption of energy and angular momentum fluxes. TH modifies the inspiral rate of the binary, and consequently, the phase and amplitude of its gravitational waveform. Numerical relativity (NR) waveforms contain these effects inherently, whereas analytical approximants for the early inspiral phase have to include them manually in the energy balance equation. In this chapter we construct a frequency-domain gravitational waveform model that incorporates the effects of tidal heating of black holes. This is achieved by recalibrating the inspiral phase of the waveform model IMRPhenomD to incorporate the phase corrections for tidal heating. We also include corrections to the amplitude, but add them directly to the inspiral amplitude model of IMRPhenomD.We show that the new model is faithful, with less than 1against a set of hybrid waveforms, except for one outlier that barely breaches this limit. The recalibrated model shows mismatches of up to 16for high mass ratios and spins. Amplitude corrections become less significant for higher mass ratios, whereas the phase corrections leave more impact – suggesting that the former is practically irrelevant for gravitational wave data analysis in Advanced LIGO (aLIGO), Virgo and KAGRA. Comparing with a set of 219 numerical relativity

waveforms, we find that the median of mismatches decreases by 4aLIGO zero-detuned high power noise curve, and by 2This implies a modest but notable improvement in waveform accuracy. Chapter 5: Horizon Parameters in Inspiral-Merger-RingdownWaveforms Inspiral-merger-ringdown (IMR) gravitational waveforms, as discussed in Chap- ter 4, are important for binaries heavier than 12M, above which merger-ringdown parts of a GW signal contribute significantly to the SNR. Using data from NR simulations, these waveforms feature an accurate description of the late inspiral and merger phases. In Chapter 3, we showed that the future GW detectors Einstein Telescope and Cosmic Explorer will be able to estimate them much better than the current detectors. We used an inspiral-only approximant for our analyses in that chapter, truncating it at the innermost stable circular orbit (ISCO). In Chapter 4, we have prepared a full IMR gravitational waveform model, based on the approximant IMRPhenomD, that includes the corrections in phase and amplitude in the frequency domain due to the tidal heating of black holes. However, the final model, referred to as IMRPhenomD Horizon, is valid exclusively for BBHs since there are no free parameters quantifying the possible presence of horizonless objects. This chapter aims to build upon that work to construct a waveform model with these parameters introduced. We demonstrate the modeling strategies for fitting NR data with phenomenological ansatz with pseudo-PN term that capture the high-frequency behaviour. We also calculate the effects in the frequency-domain phase of the waveforms with the model of TH fluxes. Chapter 6: Conclusion In the last chapter, we summarize the findings in the thesis.

Bikram Keshari Pradhan

Study of the effect of Neutron Star composition on fluid oscillation modes and Gravitational Wave emission.

Neutron stars (NS) serve as key laboratories for studying matter under extreme conditions such as strong gravitational and magnetic elds, high density, isospin asymmetry, and extreme temperatures. Despite advancements in theoretical models, terrestrial experiments, and astrophysical observations, the core of NS remains poorly understood due to signicant uncertainties in extrapolated theoretical models and limited observational data. With the interior composition of the NS core uncertain, it is conjectured that strangeness in the form of hyperons or deconned quark matter may appear at such high densities, aecting several NS observable properties. Hence, astrophysical observations of NSs are crucial in understanding dense NS matter. Neutron stars are a rich source of gravitational waves (GWs). Any system with a time-varying quadrupole moment, such as binary neutron star (BNS) mergers or non-radial oscillations of NSs, may emit GWs. The detection of GWs from the BNS merger event GW170817 signicantly enhanced the role of GW astronomy in studying NS physics. Tidal deformation in BNS mergers correlates with NS radii as well as oscillation modes, and provides independent constraints on NS radii. The GW signals and the mode characteristics (frequency and damping time) of the NS oscillation modes depend on the NS structure, interior physics, equation of state (EOS), rotation, crust properties, magnetic elds, and dissipative eects like viscosity. This concept, known as GW-asteroseismology, enables GW measurements from oscillating NSs to infer NS properties, NS EOS, and the physics of the NS interior. Furthermore, with the increasing sensitivity of current detectors and the upcoming next-generation GW detectors, it may be possible to directly observe the GWs from oscillating NSs, ushering in the era of GW-asteroseismology. Consequently, understanding the oscillation modes of NS,the effect of NS composition on the oscillation spectra, their detectability from isolated or binary systems, and the techniques of GW-asteroseismology are crucial. This thesis explores fundamental aspects of NS GW-asteroseismology involving the NS uid oscillation modes within a realistic NS EOS framework, which allows us to probe correlations of the mode characteristics with underlying nuclear properties. We study the non-radial uid oscillation modes of NS within the general relativistic (GR) framework, investigating the im-

portance of GR over the relativistic Cowling approximation for GW astronomy. This thesis explores the impact of strange baryons or "hyperons" on f-modes oscillations and discusses the ability of future f-mode detections to indicate the presence of hyperons in the NS core. We revisit the problem of NS asteroseismology and provide EOS-independent or Universal Relations (URs) between f-mode characteristics and global NS parameters by considering the present uncertainties in the nuclear and hyper-nuclear parameters and imposing state-of-the-art astrophysical constraints. Employing a Bayesian approach, the thesis addresses the inverse problem of NS asteroseismology using potential f-modes GW events from isolated glitching pulsars to constrain nuclear parameters and the NS EOS. Additionally, the potential detection of a deconned quark phase and "twin stars" (compact stars with the mass same as a NS but different radii) via f-modes GW detection from compact stars and investigating the nature of hadron-quark phase transition is explored. In the context of BNS systems, the thesis examines the impact of higher-order tidal deformation and f-mode dynamical tidal corrections on inferred NS properties, providing EOS-insensitive relations and demonstrating that neglecting f-modes dynamical corrections can bias inferred NS properties and aect the precisely measured nuclear physics and NS EOS from BNS sources. Finally, the thesis also addresses the possibility of dierentiating selfbound strange (quark) stars (SS) from NSs using GWs from binary compact star systems, proposing that simultaneous measurements of f-modes frequency and tidal deformability could distinguish SSs from NSs.

Premvijay V.

Interplay of galaxy formation and the evolution of dark matter haloes in the cosmic web.

Dark matter haloes contain a multitude of information about cosmology, particle physics, and galactic astrophysics. This thesis attempts to decouple the astrophysical effects on the radial distribution within haloes. We statistically explore this relaxation response across various haloes in realistic cosmological simulations from IllustrisTNG and EAGLE. We characterize them accurately with a simple quasiadiabatic model that accounts for astrophysical feedback effects and an explicit dependence on halo-centric distance. Through extensive CAMELS simulations, we analyze how variations in feedback implementation affect halo relaxation across different epochs, revealing insights into the underlying physical mechanisms. While the amount of feedback outflows has a strong effect on relaxation, their exact nature seems irrelevant. EAGLE simulations with a variety of astrophysical models further show that the gas equation of state strongly influences relaxation alongside feedback effects. By examining the dynamical evolution of relaxation in halo populations from $z = 5$ to $z = 0$, we statistically investigate possible causal connections with astrophysical processes such as star formation, and the production of wind and metals. These connections typically manifest immediately in inner regions, but with a 2 to 3 Gyr delay in the outer halo, elucidating the dependence on halo-centric distance. These findings can enhance baryonification schemes and semi-analytical models. Lastly, we develop a spherical self-similar model, incorporating radiative cooling and artificial viscosity to accreting gas, that mimics the formation of a galaxy disk. By evolving gas and dark matter self-consistently, we produce halo relaxation responses in this tractable system that qualitatively match full simu-sparsely placed templates is used to rapidly scan the parameter space and identify the region where a GW signal could lie. Once this region is identified, a second-stage search is conducted in the neighborhood of the identified parameter space using densely placed templates. By performing the search in two stages, the effective number of templates is reduced, significantly improving the search speed compared to the standard PyCBC search.

The hierarchical search methodology is particularly effective in scenarios where the parameter space expands significantly. A key challenge addressed in this methodology is the assignment of significance to GW events.

lations. Initial applications reveal that, besides accretion rate, the gas equation of state significantly affects halo relaxation, aligning with findings from EAGLE simulations.

Parisee Sunil Shirke

An Investigation of Beamed Emission from Binary Accreting X-ray Pulsars.

The thesis presents investigations of numerical simulations of model pulse profiles of accreting strongly magnetized neutron stars i.e. X-ray pulsars. A new, fully comprehensive, custom numerical simulator is developed that accounts for all anisotropic, thermal, vacuum, extended emission geometric and general relativistic effects. Using model pulsar emission beams, the study incorporates (i) a full range of beaming angles, (ii) an updated general relativistic light bending and gravitational red-shift for point hotspots, (iii) composite with surface integration over extended circular slabs on the polar caps of the pulsar (iv) over the full span of fractional compact stellar surface coverage. For theoretical completeness and reference base, this treatment is applied to isotropic, uniform emitters, as well. The simulations are compared with existing X-ray timing observations of a model pulsar Centaurus X-3, available with the AstroSat space mission. This exercise is reversed to draw systemic inferences, too, demonstrating the importance of the inclusion of light bending in pulsar simulations. Given the current X-ray polarimetric research trends, a possible extension of this work to polarisation-resolved studies is outlined in detail as a proof-of-concept. Exploiting the promise of pulsars as rich astrophysical laboratories, the free-free Gaunt factors for a hot, magnetized plasma in non-LTE conditions, including anisotropic effects found in model pulsar atmospheres are also calculated. The thesis provides each of the aforementioned computation results for a wide range of source pulsar configurations. Such research aims to take a step towards addressing the existing pencil and fan beam degeneracy and ultimately, towards a unified theory for pulse profile formation, spectra and polarisation in binary accreting X-ray pulsars over a wide range of accretion luminosities.

Kanchan Soni

Efficient searches for compact binary coalescences and science in the LIGO-India era.

Gravitational waves (GWs), predicted by Albert Einstein's Theory of General Relativity, provide a unique window into astrophysics and cosmology. These waves were first indirectly detected through the discovery of binary pulsar B1913+16 by Hulse and Taylor in 1994. It was a century later that GWs from merging compact binaries were directly observed with the establishment of the Laser Interferometer Gravitational-Wave Observatory (LIGO) and Virgo. GWs are emitted when two compact objects, like black holes or neutron stars, spiral inward and merge, creating a characteristic chirp signal detectable by interferometers. This unique frequency-time evolution of GWs from compact binary coalescences (CBCs) allows for detailed numerical study. To date, nearly 90 GW sources have been cataloged by the LIGO-Virgo-KAGRA (LVK) collaboration, mostly detected using a matched filtering technique. This technique involves correlating the detector's time-series data with modeled waveforms

(templates) to identify GW signals. The matched filtering signal-to-noise ratio (SNR) confirms a GW event when observed across multiple detectors. Since the precise dynamics of GW sources are unknown, matched filtering is performed over a broad bank of templates representing various potential sources, including binary black hole, binary neutron star, and neutron star-black hole mergers.

The computational demand for matched filtering grows with the complexity of the parameter space and the number of templates. To reduce computation time, current searches focus on sources with quasi-circular orbits and aligned spin systems, limiting the parameter space and size of the template bank. Including factors like orbital precession and eccentricity would increase the template bank size and computational cost, but detecting such binaries is crucial for understanding formation channels and challenging current astrophysical theories.

With advancements in current detectors and development of the next-generation detectors such as the Cosmic Explorer and Einstein Telescope, the detection rate of CBCs will rise, necessitating faster search pipelines for longer signal durations and larger parameter spaces.

In my thesis, I developed a two-stage hierarchical search pipeline, an efficient methodology for detecting GW signals from CBCs. This search methodology operates in two stages. In the first stage, a coarse template bank with In my thesis, I proposed a semi-analytical approach for background estimation, a crucial step in estimating the significance of GW events. We demonstrated its efficacy by applying our developed search pipeline as a proof of concept to detect subsolar mass compact objects within LIGO data. Our results showed a 10-15

The upcoming LIGO-India detector in India is poised to play a pivotal role. It is expected to detect a significantly higher number of compact binary mergers, dramatically improving CBC source localization. Enhanced localization capabilities for binary neutron star (BNS) mergers will facilitate the detection of more electromagnetic (EM) counterparts, thereby refining the upper limits on the Hubble constant value. In this context, the last part of my thesis focuses on the advantages of adding a LIGO-like detector in India. Specifically, we investigate how much LIGO-India can contribute to achieving precise measurements of the Hubble constant. This segment of the work is crucial in understanding the potential impact of LIGO-India on future gravitational wave astronomy and cosmological research.

To address this problem, we performed an end-to-end simulation with A+ sensitivities for a network of detectors including LIGO Hanford, LIGO Livingston, Virgo, and LIGO-India. Using this sensitivity, we simulated the noise. We injected simulated GW signals from binary neutron star (BNS) mergers. The injected signals were recovered using a low-latency pipeline called PyCBC Live, which performs a comprehensive matched filtering search over a bank of templates on the simulated data. Detected sources were subjected to realistic EM observations using the gwemopt toolkit for telescopes like Zwicky Transient Facility (ZTF), Vera C. Rubin Observatory Legacy Survey of Space and Time (LSST), and Wide-field Infrared Transient Explorer (WINTER). Assuming a kilonova light curve for a BNS merger, we localized sources in different bands of telescopes. With the number of localized sources obtained, we explored the question: How many years will it take to achieve 2% accuracy in measuring the Hubble constant?

Our results showed that with LIGO-India operating alongside the other two LIGO detectors and Virgo, the BNS detection rate with electromagnetic counterparts would increase by 2 to 7. This improvement comes from two aspects. The first is the increased SNR due to four detectors operating simultaneously. The second, and more significant, factor is the improvement in localization as the effective baseline is longer when LIGO-India is included in the network. Assuming a BNS merger rate of one per year, we found that it would take nearly 20 years to achieve 2% accuracy in the Hubble constant value with LIGO-India.

Computing Facility

The IUCAA Computing Facility offers state-of-the-art computing hardware and a technology-rich environment for IUCAA members, associates and visitors. It also extends an array of specialised High-Performance Computing (HPC) environments to the academic community for their research.

The hardware and devices currently managed by the computing facility include about 350+ servers and desktops, 100+ laptops, 80+ printers and scanners, three large High-Performance Computing systems and over 9.5 PiB of storage, in addition to diverse equipment deployed for an extensive, high-throughput, wired and wireless campus-wide network. The number of registered Wi-Fi devices is over 900, and e-mail accounts served by the computing facility are nearly 825.

IUCAA provides e-mail services to its members and associates, with a total of nearly 825 accounts. IUCAA has its own registered domain name as "iucaa.in" and "ligo-india.in", also managing different domains for different groups and or projects, viz "associates.iucaa.in", "gw.iucaa.in", "lisc.iucaa.in", and "mailman.gw.iucaa.in". The WAN services are provided by the National Knowledge Network over a 1 Gbps fibre connectivity, with a fallback arrangement over a 50 Mbps line from BSNL.

In the year April 2024 - March 2025, emphasis was given to the implementation of:

1) Expansion of the Pegasus cluster

The Pegasus cluster, deployed in 2019, consists of two head nodes, four login nodes, two graphics nodes, four GPU nodes, 2560 compute cores, and 2PiB Parallel File System (PFS) storage. Several new users have been added in the last two years, and all users use the cluster extensively. The average cluster utilisation is more than 90%, resulting in a considerable wait time for many jobs. To cater for the ever-increasing need for computing power for large-scale computational jobs and reduce the wait time, the Pegasus cluster was augmented by adding 20 compute nodes.

2) Replacement of OLD C-Power L&T Air Circuit Breakers

IUCAA has two dedicated 1250 Amps C-Power L&T Air Circuit Breakers, providing power supply to the new data centre; IT and non-IT equipment are 12+ Years old and declared at the sale's end, thus finding it difficult to replace the parts and maintenance, leading to recurring failure of the power supply results in a power outage in the new data centre affecting the services hosted in the data centre. Considering the future power requirement and improving the power supply stability in the data centre, the existing C-Power ACB L&T Circuit Breakers were replaced with two new, higher-capacity (1600A) C-Power L&T Air Circuit Breakers.

3) Constitution and Implementation of Time Allocation Committee (TAC) for Pegasus cluster

IUCAA has a dedicated cluster to support IUCAA members, associates, and their students across the inter-universities with their high-performance computing execution and data processing. IUCAA associates and international users highly utilize the HPC cluster. As the number of users, projects, and the complexity of the problems being addressed continue to grow, the computing demands are escalating rapidly and significantly. To streamline the usage and ensure equitable prioritisation of both projects and groups/users, the Computer Users Committee has approved a bi-annual proposal for the allocation of HPC resources, divided into two periods: January-June and July-December. A time allocation committee was formed to deliberate and allocate resources efficiently across the various project groups/users, and implemented on IUCAA HPC to allocate the resources.

4) Renewal of Astronomical software services.

Scientists at IUCAA carry out research in a wide range of Astronomy and Astrophysics, such as Classical and quantum gravity, Cosmic magnetic fields, cosmology, large-scale structure, Galactic and extragalactic astronomy, Gravitational waves, High energy astrophysics, Instrumentation for astronomy, Observational Astronomy (Optical, UV, X-ray, and Radio), Quantum metrology for precision measurements, Solar Physics, and many more. Many of these fields require high-level data visualisations from complex numerical data. To help create such meaningful visualisations, IUCAA procured the licenses for Mathematica, MATLAB, and IDL software services.

The Computer Centre continues to provide technical support to IUCAA associates, project students, as well as visitors from universities and institutions within India and abroad.

The Computing Facility employs 10 personnel, who carry out the daily functions that include:

1. Architecting the overall IT solution/technologies required for IUCAA and presenting it to the Computer Facilities Committee for consensus.
2. Framing policy documents and finalizing them in consultation with the Computer Facilities Committee members.
3. Drawing up specification of the RFP (Request For Proposal) tender document for IUCAA IT required to be purchased, and oversee all purchase-related procedures and follow up.
4. Maintenance of IT hardware on the campus, including servers, desktops,

mobile computing equipment, printers, etc.

5. Providing in-house design, development and maintenance support to the Administrative Office automation software (iOAS) and IUCAA website. (Designed web portals consisting online application module for various workshops.)

6. Maintaining Zimbra email servers and mirror sites hosted at IUCAA, and their day-to-day administration.

7. Configuration and management of data backups.

8. Design, management and administration of network topology and firewall rules.

9. Administration of Ruckus wireless network covering the entire office as well as residential campus. Providing end users support for Wi-Fi devices such as laptops, mobile devices.

10. Day to day administration of Virtualization infrastructure and various servers catering to Administration such as AD, etc.

11. Maintenance of Video Conferencing equipment and end user support.

12. Management of inventory of computer center consumable items and Assets and Furniture and its tracking.

13. Procurement of SSL certificates and software for all the relevant web servers at IUCAA.

14. End user service support to Administrative staff, Academic members, Visitors and Associates.

15. Infrastructure, management and coding support to IT intensive projects such as LIGO, MALS, SUIT, AstroSat, Big Data etc.

16. Procurement, installation and periodic upgradation of mathematical software such as Matlab, IDL, Mathematica meant for general IUCAA users and cluster users.

17. Procurement of Printers (Qty. 10), All in one Desktops (Qty 20), Laptops (Qty. 3), MacOS devices (Qty. 8) for the academic community, visitors and administrative officers.

18. Hardware Maintenance and General System Administration of clusters in IUCAA in coordination with OEM.

19. Assisting Library department to maintain their IT infrastructure.

20. Hosted GitLab for IUCAA users and associates.

21. Architecting new hardware solutions to address operational needs.

High Performance Computing

IUCAA currently has three major independent HPC clusters dedicated to different applications, namely Pegasus, SARATHI and VROOM.

The **Pegasus Cluster** is to serve the general computing requirements of the astronomy community associated with IUCAA. It has 100 compute nodes, 4 GPU nodes with 32 cores and 384 GB (on old) & 512GB RAM (on new). It uses InfiniBand EDR (100 Gbps) as an interconnect, and Portable Batch System (PBS) as a job scheduler. For visualisation purposes, there are two dedicated graphics nodes equipped with NVIDIA Tesla P100 GPU cards. The cluster consists of more than 2600 Physical cores. The cluster is attached to a 2 PiB parallel file system (Lustre), which is capable of delivering 15 Gbps throughput. The theoretical computing speed of the Pegasus Cluster is 150 TF. The Pegasus cluster has been utilised by about 70 high-volume users from IUCAA and various Indian Universities, running applications for Molecular Scattering, Molecular Dynamics, Stellar Dynamics, Gravitational N-Body Simulations, Cosmic Microwave Background Evolution, Fluid Mechanics, Magnetohydrodynamics, Plasma Physics, and the analysis of diverse astronomical data.

The **Sarathi Cluster** is primarily used for gravitational wave research and is mostly used by national and international members of the International Gravitational-Wave Observatory Network (IGWN), previously known as the LIGO Scientific Collaboration (LSC), which includes many IUCAA members and Associates. The cluster is comprised of heterogeneous compute servers, and it is built in three phases. The cluster consists of more than 8000 Physical cores. The theoretical peak performance of the compute node CPUs of the cluster is nearly 530 TFlops. The cluster has 2PiB PFS storage with 30Gbps write and read (1:1) throughput.

The **Vroom cluster** is used solely for the MeerKAT Absorption Line Survey (MALS). This cluster has 21 compute nodes, 2 MDS nodes, 4 GPU nodes and 2 head nodes, which deliver 25 TF computing speed and have a parallel file system of 3.5 PiB usable capacity attached to it. The cluster is also attached to 2 PiB archival storage for archiving/serving the processed data to the international community.

HPC clusters listed in the Top Supercomputers in India

Sarathi Cluster Phase III, Pegasus Cluster, and Sarathi Cluster Phase II are listed at 36th, 50th and 53rd rank, respectively, in the list of top Supercomputers in India published on January 31, 2024. The list is maintained and supported by CDAC's Tera scale Supercomputing Facility (CTSF), CDAC, Bangalore. The list is available at https://topsc.cdacb.in/filterdetailstry?page=60&slug=January2024

IUCAA High Performance Computing clusters namly Pegasus and Sarathi.

(Picture Credit: Mr. Shashank Tarphe)

Staff of the Computing Facility at IUCAA.

(Picture Credit: Mr. Shashank Tarphe)

Chiller plant assembly for IUCAA Data centre.

(Picture Credit: Mr. Shashank Tarphe)

Power conditioning room for IUCAA Data centre with UPS, battery banks and control panels

(Picture Credit: Mr. Shashank Tarphe)

The IUCAA Library

The IUCAA library provides users access to a comprehensive collection of books and journals in astronomy, astrophysics, and related areas. The library acquired 31 new print titles and 380 eBooks from the Springer Physics and Astronomy collection for 2024-25 and renewed the subscription to Annual Reviews. The library maintained its renewals to the Grammarly Premium software and the Overleaf software, a collaborative cloud-based LaTeX editor for writing, editing and publishing scientific documents. The library renewed its subscriptions to 48 journals for 2024. Courtesy of the E-Shodh Sindhu Consortium for Higher Education Electronic Resources, MHRD, Government of India, the library continued to receive access to seven e-resources, along with two NSDL e-resources as below:

1. American Institute of Physics
2. American Physical Society
3. Institute for Studies in Industrial Development (ISID) Database
4. JGate Plus (JCCC)
5. Springer Link 1700 Collection and Nature Journal
6. Taylor and Francis
7. Web of Science

NDL e-Resources

1. World e-Book Library (Now available through NDLI only)
2. South Asia Archive (SAA) (Under National Licensing (Perpetual)

Implementation of One Nation One Subscription (ONOS)

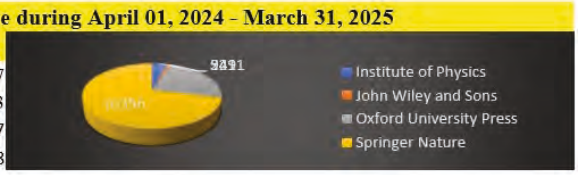
The Government of India launched the One Nation One Subscription (ONOS) scheme that aims to provide nationwide access to international scholarly journals for students, faculty, and researchers in centrally and state-managed higher education and research institutions. With ONOS, IUCAA has access to content from 30 major international publishers (listed below) beginning January 1, 2025, for an initial phase lasting through 2027. The access is coordinated by the INFLIBNET Centre, UGC, and journals are accessible via a unified portal: https://www.onos.gov.in.

List of 30 Publishers under ONOS

1. Elsevier ScienceDirect
2. Springer Nature
3. IEEE (IEL Online - Complete)
4. Wiley Blackwell Publishing
5. Taylor and Francis
6. Lippincott Williams & Wilkins (Wolters Kluwer)
7. Institute of Physics
8. American Chemical Society
9. Cambridge University Press
10. American Physical Society
11. Oxford University Press
12. BMJ Journals
13. American Institute of Physics
14. ASCE
15. Project MUSE
16. IndianJournals.com
17. ASME
18. Bentham Science
19. Cold Spring Harbor Laboratory Press
20. ACM Digital Library
21. Annual Reviews
22. ICE Publishing
23. American Society for Microbiology
24. American Association for the Advancement of Science
25. American Institute of Aeronautics and Astronautics (AIAA)
26. American Mathematical Society
27. Emerald Publishing
28. SAGE Publishing
29. SPIE Digital Library
30. Thieme Medical Publishers

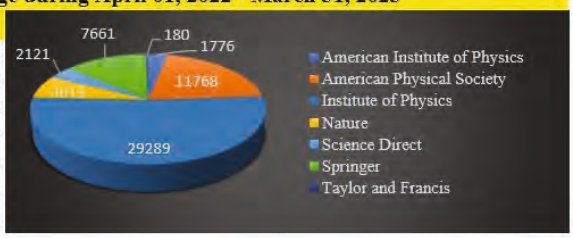
E-Books usage during April 01, 2024 - March 31, 2025

Publisher	Count
Institute of Physics	757
John Wiley and Sons	593
Oxford University Press	227
Springer Nature	21788



E-Journals usage during April 01, 2022 - March 31, 2023

Publisher	Count
American Institute of Physics	1776
American Physical Society	11768
Institute of Physics	29289
Nature	3813
Science Direct	2121
Springer	7661
Taylor and Francis	180



The library facilitates off-campus access to the following e-resources via the Remotlog software.

- **American Association of Physics Teachers**
- **American Institute of Physics**
- **American Scientist**
- **Annual Review of Astronomy and Astrophysics**
- **Applied Optics**
- **American Physical Society**
- **Cambridge University Press**
- **EDP Sciences**
- **Institute of Physics**
- **Nature**
- **New Scientist**
- **Physics Today**
- **Physics Education**
- **Popular Science**

- **Science Direct**
- **Springer Nature**
- **Taylor and Francis**
- **The Web of Science**
- **World Scientific**

In addition to the usual library business, the library team of five professionals facilitated the following activities and services:

- **VIDWAN:** The library created the profile of five academic members on the VIDWAN portal [https://vidwan.inflibnet.ac.in/] this year, taking the total profiles to forty-eight. VIDWAN is developed and maintained by the Information and Library Network Centre [INFLIBNET] with financial support from the National Mission on Education through ICT [NME-ICT].

- **IRINS** [https://iucaa.irins.org/] supports R&D institutions in curating and showcasing scholarly communications and activities through this web-based platform.

- **Open Journal System [OJS]:** The library manages and maintains the IUCAA Annual Report, Khagol and Vyom issues on the IUCAA website using OJS [http://publication.iucaa.in/].

- **Document Delivery Service**: The library fulfilled 193 article requests from 85 users.

- **Inter-library Loan Service**: The library facilitated the loan of six books on inter-library loan to three libraries.

- **Publication Charges and Memberships:** The library processed twenty-eight publication charge requests and renewed its arXiv membership for 2024-25.

- **Plagiarism Reports:** The library provided plagiarism reports using the DrillBit software for the Ph.D. thesis of fifteen students. It also provided plagiarism reports for research articles using the 'Check-for-Plag' software.

- **YouTube Channel:** The library YouTube channel https://www.youtube.com/iucaalib] features 174 videos with 8.63K subscribers and 56.2K views.

- **Publications Assistance:** Assistance to the Publications Department in compiling the Annual Report and Khagol-related content, including the list of publications by IUCAA Academics and Visiting Associates, compilation of the reports received from the various IUCAA Centres for Astronomy Research and Development [ICARD], for the 37th Annual Report.

N. Nageswaran,
Shashikant Mirkute,
Hemant K. Sahu,
Kanak Saha [Head, Library],
Vijay K. Rai and
Nirupama Bawdekar.

[Pic. Credit: Mr. Shashank Tarphe]

Astronomy Centre for Educators

Malaviya Mission Teacher Training Centre

Advances in Astronomy: Integrating Technology in Astronomy Research

A short-term online workshop titled Advances in Astronomy: Integrating Technology in Astronomy Research was held from April 01 - 05, 2024, in collaboration with the Vishwakarma Institute of Information Technology, Pune. The workshop was coordinated by Tushar R. Jadhav, Milind S. Patil, Mandar S. Karyakarte, and Gajanan H. Chavhan from Vishwakarma Institute of Information Technology and Team Astronomy Centre of Educators (ACE), IUCAA.

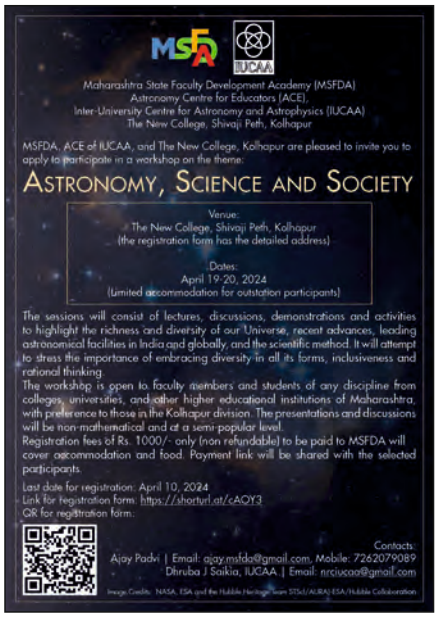
(For details, see Khagol 133, July 2024)

A section of the participants and the poster announcement

Astronomy, Science and Society

A workshop on the theme of Astronomy, Science and Society was organised on April 19 - 20, 2024, at The New College, Kolhapur, by the Maharashtra State Faculty Development Academy (MSFDA) and the Astronomy Centre for Educators of IUCAA. The workshop was organised by Apurva Barve, Kalyani Gokhale, and Kabeer Palshikar from MSFDA, as well as Team ACE, IUCAA.

(For details, see Khagol 133, July 2024)

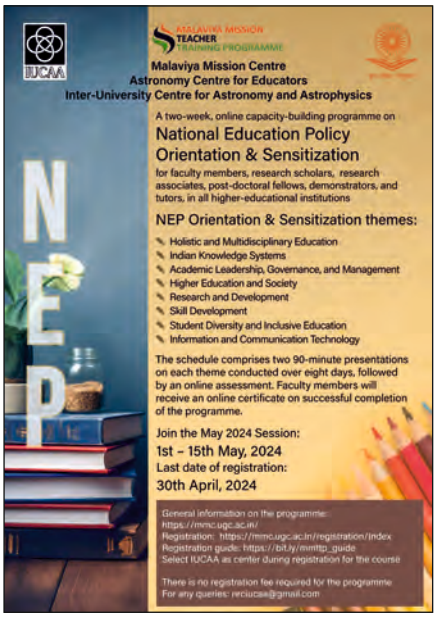


A group photograph of the participants with the Principal of The New College and the poster announcing the programme at The New College, Kolhapur

National Education Policy (NEP) Orientation and Sensitisation Programmes

An NEP Orientation and Sensitisation Programme under the Malaviya Mission Teacher Training Programme was held online from May 01 - 05, 2024. About 200 participants attended the programme.

(For details, see Khagol 133, July 2024)

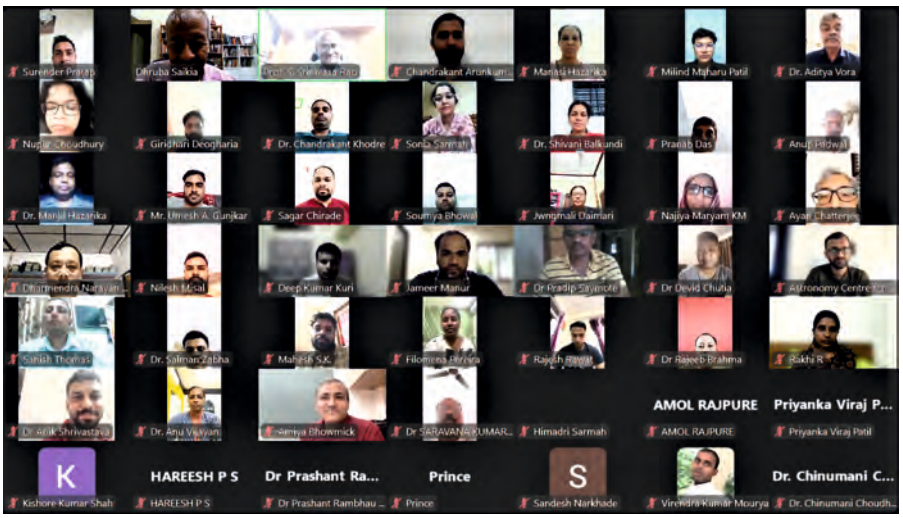


A screenshot of a section of the participants and the poster announcement

National Education Policy (NEP) Orientation and Sensitisation Programmes

An NEP Orientation and Sensitisation Programme under the Malaviya Mission Teacher Training Programme was held online from 1st to 15th July 2024. There were about 90 participants in the programme.

(For details, see Khagol 134, October 2024)

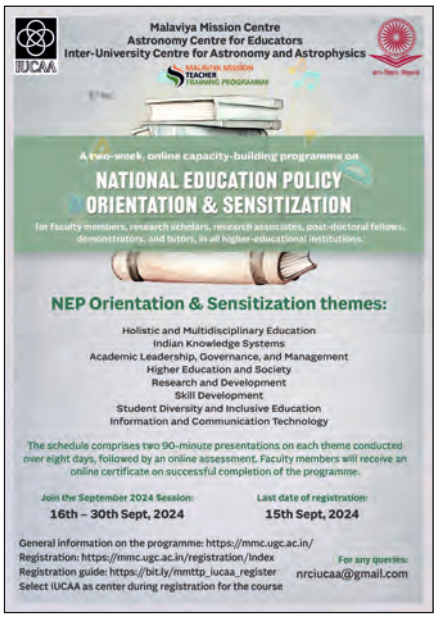


Science, Astronomy and Society

A workshop on the theme of Science, Astronomy and Society, was organised from September 03 – 05, 2024, by the Maharashtra State Faculty Development Academy (MSFDA) and the Astronomy Centre for Educators of IUCAA at MSFDA, Pune. The workshop had about forty participants, including resource persons and organisers. This was organised by Suraj Babar and Ganesh Bhise from MSFDA and Team ACE, IUCAA.

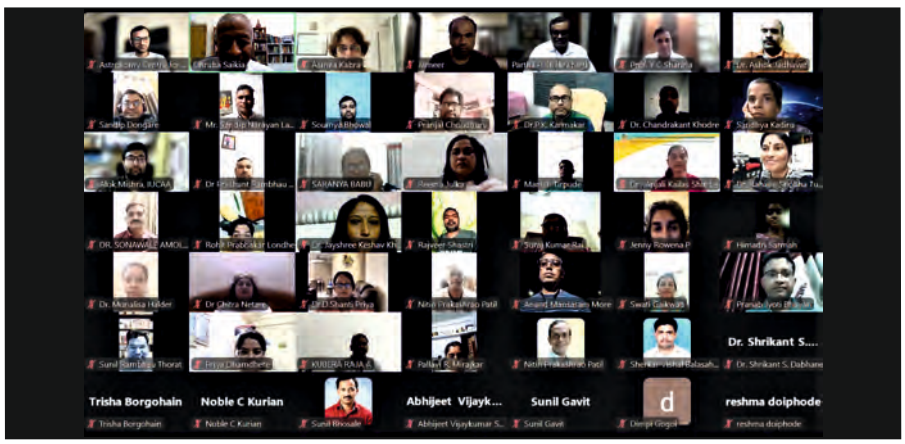
(For details, see Khagol 134, October 2024)

National Education Policy (NEP) Orientation and Sensitisation Programmes



An NEP Orientation and Sensitisation Programme under the Malaviya Mission Teacher Training Programme was held online from September 16 - 30, 2024. There were about 90 participants in the programme.

(For details, see Khagol 134, October 2024)



Astronomy-themed experiments competition

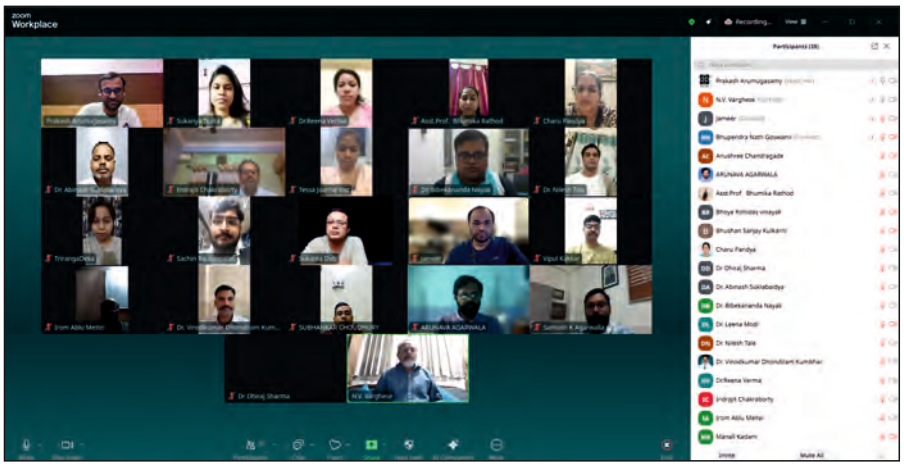
An astronomy-themed experiments competition was announced in August 2024, with the last date of registration being September 23, 2024. The last date for submission was December 31, 2024. The competition aimed to design astronomy-themed experiments for undergraduate and postgraduate laboratories in institutions of higher education, including engineering institutions.

(For details, see Khagol 134, October 2024)

National Education Policy – 2020: Orientation and Sensitisation

The Malaviya Mission Teacher Training Centre (MMTTC) of the Astronomy Centre for Educators (ACE) conducted a two-week online capacity-building programme on the National Education Policy – 2020: Orientation and Sensitisation. The programme was scheduled from November 15 to November 30, 2024.

(For details, see Khagol 135, January 2025)



Workshop on Astronomy, Science, and Society

A two-day workshop on *Astronomy, Science, and Society* was jointly organised by the Maharashtra State Faculty Development Academy (MSFDA), Pune, and the Astronomy Centre for Educators (ACE) of IUCAA at G.H. Raisoni International Skill Tech University, Pune, on February 20–21, 2025. This recurring program, conducted several times a year across different regions of Maharashtra, is designed for faculty members from all academic disciplines—sciences, arts, humanities, and professional courses—in institutions of higher education. The workshop was coordinated by Surajkumar Babar, Bhargav Valanju, and Rutuja Tambe from MSFDA, in collaboration with Team ACE from IUCAA. The event effectively combined scientific exploration with interdisciplinary engagement, offering participants a broadened understanding of astronomy and its relevance to society.

(For details, see Khagol 136, April 2025)

SPONSORED MEETINGS AND EVENTS OUTSIDE OF IUCAA

Introductory Workshop on Astrophysics and Cosmology

The Introductory Workshop on Astrophysics and Cosmology was held from May 02 to 04, 2024, at Integral University, Lucknow, in collaboration with IUCAA. The workshop was coordinated by M. Shahalam (Integral University) and Aseem Paranjape (IUCAA).

(For details, see Khagol 133, July 2024)

High-Performance Computing in Science

The three-day workshop on High-Performance Computing in Science, organised by ICARD, University of Kashmir, in collaboration with IUCAA, was held from May 22 - 24, 2024. Sixty M.Sc. students participated in the workshop. The workshop was coordinated by Manzoor A. Malik (University of Kashmir) and Sanjit Mitra (IUCAA).

(For details, see Khagol 133, July 2024)

Summer School in Theoretical (Astro) Physics

The Department of Physics and Electronics at St. Xavier's College (autonomous), Ahmedabad, in association with Kshama (Ahmedabad Academy of Sciences), organised a six-day Summer School in Theoretical (Astro)Physics from June 03 - 8, 2024. The School was coordinated by Gurudutt Gaur (St. Xavier's College, Ahmedabad) and Sanjit Mitra (IUCAA).

(For details, see Khagol 133, July 2024).

Workshop on Relativistic Cosmology: Theoretical and Data Analysis Techniques

The Centre of Excellence for Astrophysics and Cosmology at G. H. Raisoni College of Engineering, Nagpur, in collaboration with IUCAA, organised a three-day workshop on Relativistic Cosmology: Theoretical and Data Analysis Techniques from July 15 - 17, 2024. The workshop was organised by Praveen Kumar Dhankar (G.H. Raisoni College, Nagpur) and Surhud More (IUCAA).

(For details, see Khagol 134, October 2024)

Introductory Workshop on Active Galactic Nuclei and Blazars

An introductory workshop on Active Galactic Nuclei and Blazars was held at Presidency University, Kolkata, from July 22 - 23, 2024. The workshop was coordinated by Vaidehi Paliya (IUCAA) and Ritaban Chatterjee (Presidency University).

(For details, see Khagol 134, October 2024)

Conference on Blazars and Restless Active Galactic Nuclei (COBRA): A High Energy View

The Conference on Blazars and Restless Active Galactic Nuclei (COBRA): A High Energy View was held at Presidency University, Kolkata, from July 24 - 26, 2024. The conference was coordinated by Vaidehi Paliya (IUCAA) and Ritaban Chatterjee (Presidency University).

(For details, see Khagol 134, October 2024)

Probing Stars and Galaxies using Innovative Data Science Tools

The Department of Applied Sciences, Gauhati University, in collaboration with IUCAA, ANRF, and NIF, organised a workshop titled 'Probing Stars and Galaxies Using Innovative Data Science Tools' from September 4 - 6, 2024. It was coordinated by Eeshankur Saikia (Gauhati University) and Anupam Bhardwaj (IUCAA).

(For details, see Khagol 134, October 2024)

Contemporary Issues in Astronomy and Astrophysics

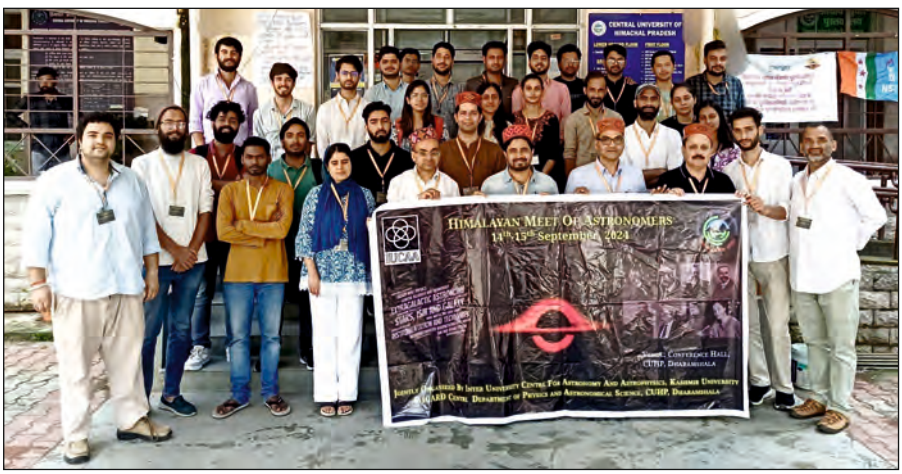
The Department of Physics, Shivaji University, Kolhapur, in collaboration with IUCAA, organised a national workshop titled 'Contemporary Issues in Astronomy and Astrophysics 2024 (CIAA 2024)' from September 13 - 15, 2024. The workshop was coordinated by Siba Prasad Das (Shivaji University) and Sanjit Mitra (IUCAA).

(For details, see Khagol 134, October 2024)

2nd Himalayan Meet of Astronomers (HMA) 2024

A two-day Himalayan Meet of Astronomers was held on September 14 - 15, 2024, at the Central University of Himachal Pradesh (CUHP), Dharamshala. It was jointly organised by the University of Kashmir, ICARD (IUCAA Centre for Astronomy Research and Development), CUHP's Department of Physics and Astronomical Sciences, and IUCAA, Pune. The event was coordinated by Hum Chand (CUHP), Naseer Iqbal (University of Kashmir) and Ranjeev Misra (IUCAA).

(For details, see Khagol 134, October 2024)



International Conference on "Neutron star Equation Of State and Gravitational Waves" (NEOSGrav2024)

The International Conference on 'Neutron Star Equation of State and Gravitational Waves' (NEOSGrav2024) was organised by IUCAA from October 01 - 04, 2024, at the Kenilworth Hotel, Goa. The conference was coordinated by Debarati Chatterjee (IUCAA).

(For details, see Khagol 135, January 2025)

Gravitational Waves and LIGO-India

A five-day introductory workshop on 'Gravitational Waves and LIGO-India' was held at BITS Pilani, Pilani campus, from October 15 - 19, 2024. It was organised by IUCAA and the Department of Physics, BITS Pilani. The workshop was coordinated by Apratim Ganguly (IUCAA) and Sajal Mukherjee (BITS Pilani).

(For details, see Khagol 135, January 2025)

North East Meet of Astronomers (NEMA) - X

The North East Meet of Astronomers (NEMA) – X was held at Tezpur University from October 23 - 25, 2024. NEMA-X marked the 10th anniversary of this annual astronomy gathering, fostering collaboration across North East India. The event was coordinated by Rupjyoti Gogoi (Tezpur University) and Ranjeev Misra (IUCAA).

(For details, see Khagol 135, January 2025)

Workshop on Gravitation and Cosmology

The Workshop on Gravitation and Cosmology was held from October 23 - 25, 2024, at DDU Gorakhpur University. It was organised by the Department of Mathematics and Statistics in collaboration with ICARD and sponsored by IUCAA. The workshop was coordinated by Rajesh Kumar (DDU, Gorakhpur University, Gorakhpur) and Apratim Ganguly (IUCAA).

(For details, see Khagol 135, January 2025)

Conference on Classical and Quantum Gravity

The Conference on Classical and Quantum Gravity was held from November 05 - 07, 2024, at the Department of Physics, Cochin University of Science and Technology (CUSAT), Kochi. The conference also celebrated the significant contributions of Naresh Dadhich to the field of gravity and black hole physics on his 80th birthday. The conference was coordinated by Joe Jacob (Newman College), Charles Jose (CUSAT), and Dawood Kothawala (IIT, Madras).

(For details, see Khagol 135, January 2025)

Introductory workshop on Astronomy and Astrophysics

The 'Introductory Workshop on Astronomy and Astrophysics' was held at Cochin College, Kerala, from November 13 - 15, 2024, in collaboration with IUCAA, Pune. Forty-eight students from twenty-five colleges affiliated to M.G. University and the University of Calicut, Kerala, Jain University, Christ University, Bengaluru, etc., participated in the workshop. The workshop was coordinated by Sathya Narayanan (Cochin College) and Anupam Bhardwaj (IUCAA).

(For details, see Khagol 135, January 2025)

General Relativity: A century of observations

A three-day workshop titled 'General Relativity: A Century of Observations (GR-COBS)' was held at Malda College, West Bengal, in collaboration with IUCAA from November 21 - 23, 2024. It was coordinated by Shyam Das (Malda College) and Surhud More (IUCAA).

(For details, see Khagol 135, January 2025)

Empowering Teachers to Foster Scientific Curiosity in Students - A Joint Initiative of STEM & Space and ARIES

A unique training program titled 'Empowering Teachers to Foster Scientific Curiosity in Students' was jointly organised by STEM & Space, New Delhi, ARIES, Nainital, with the support from the Office of Astronomy Education (OAE), India, from November 25 - 27, 2024. The program was coordinated by Surhud More (IUCAA).

(For details, see Khagol 135, January 2025)

High Energy Astrophysics Workshop

A three-day workshop on High Energy Astrophysics was held from November 25 - 27, 2024, jointly organised by the Department of Physics, Banaras Hindu University, and IUCAA. The workshop was coordinated by Raj Prince (Banaras Hindu University) and Vaidehi Paliya (IUCAA).

(For details, see Khagol 135, January 2025)

Introductory Workshop on Solar Astronomy

A two-day workshop on Solar Astronomy was held at Patna University on November 29 - 30, 2024, in collaboration with IUCAA. The workshop was coordinated by Sumita Singh (Patna University), Sanjay Kumar (Patna University) and Durgesh Tripathi (IUCAA).

(For details, see Khagol 135, January 2025)

Workshop on Teaching Astronomy in State Board Schools in and around Mumbai: Train the Trainer

The Workshop on Teaching Astronomy in State Board Schools in and around Mumbai: Train the Trainer was organised by Sky Explorers, in collaboration with the Nehru Planetarium, Worli, Mumbai, from December 06 - 07, 2024. The workshop was coordinated by Surhud More (IUCAA).

(For details, see Khagol 135, January 2025)

IAU - Astronomy for Education Teacher Training Program 2025

The Tamil Nadu Astronomy & Science Society (TASS) and the Indian Institute of Astrophysics (IIA), Bengaluru, organised a Teacher Training Program supported by OAE-Centre India from December 6 - 8, 2024, at Bishop Heber College, Tiruchirappalli, Tamil Nadu. The workshop was coordinated by Surhud More (IUCAA).

(For details, see Khagol 135, January 2025)

Manipal-IUCAA Astrostatistics School - 2024

The Manipal Astrostatistics School (MAS 2024) was held from December 10 - 15, 2024, at the Manipal Centre for Natural Sciences, MAHE. The school was organised in collaboration with Pennsylvania State University and IUCAA. The school was coordinated by Debbijoy Bhattacharya (MAHE) and Ranjeev Misra (IUCAA).

(For details, see Khagol 135, January 2025)

Gravity@2024

A national-level conference 'Gravity@2024' was held from December 18 - 20, 2024, at the IUCAA Centre for Astronomy Research and Development (ICARD), Department of Physics, Cooch Behar Panchanan Barma University. The conference was coordinated by Ranjan Sharma (ICARD, CBPBU) and Kanak Saha (IUCAA).

(For details, see Khagol 135, January 2025)

Introductory Workshop on Astronomy and Astrophysics

An introductory workshop on Astronomy and Astrophysics, sponsored by IUCAA, Pune, was held at the Department of Physics, Dolphin PG Institute of Biomedical and Natural Sciences (DIBNS), Dehradun, from December 18 – 20, 2024. The workshop was coordinated by Aasheesh Raturi (DIBNS) and Anupam Bhardwaj (IUCAA).

(For details, see Khagol 135, January 2025)

National Conference on Data Science Innovations in Astronomy (NCDSIA)

The National Conference on Data Science Innovations in Astronomy (NCDSIA) was held on January 03 - 04, 2025, at Amity University Kolkata. It was jointly organised by Amity University and ICARD Kolkata, and sponsored by IUCAA, Pune. The conference was coordinated by Abisa Sinha (Amity University) and Asis K. Chattopadhyay (University of Calcutta).

(For details, see Khagol 136, April 2025)

Focused Meeting on Cosmology and Gravitation

The focused Meeting on Cosmology and Gravitation was held from January 8 to 10, 2025, at Gauhati University in collaboration with IUCAA, Pune. The primary aim of the meeting was to commemorate the century of developments in cosmology since Friedmann's publication of the first relativistic expanding cosmological models between 1922 and 1924. The meeting was coordinated by Sanjeev Kalita (ICARD Coordinator, Gauhati University) and Kanak Saha (IUCAA).

(For details, see Khagol 136, April 2025)

Radio Astronomy School

The Radio Astronomy School was held from February 17 - 24, 2025, at the Fergusson College, Pune, under the aegis of the IUCAA Centre for Astronomy Research and Development (ICARD). The school was coordinated by Manish S. Hiray and Gajanan D. Harale, with overall guidance from Raka Dabhade. The event brought together forty selected undergraduate and postgraduate students from seven institutions across Maharashtra, chosen from seventy-eight applicants.

(For details, see Khagol 136, April 2025)

Exhibition: On the Shoulders of Giants

As part of ICARD activities at Fergusson College, Pune, a two-day exhibition titled '*On the Shoulders of Giants*' was held on January 15–16, 2025. The exhibition was coordinated by Raka Dabhade and conceptualised and executed entirely by undergraduate students of the Department of Physics. The exhibition not only engaged a wide audience but also provided students with hands-on experience in science communication, teamwork, event management, and public engagement. It fostered a deeper understanding of physics and inspired curiosity in both participants and visitors.

(For details, see Khagol 136, April 2025)

Tenth Southern Regional Astronomy Meeting: Astronomy Research – Opportunities and Challenges

The Tenth Southern Regional Astronomy Meeting, titled *Astronomy Research: Opportunities and Challenges*, was held from January 31 to February 2, 2025, at the Department of Physics, Cochin University of Science and Technology (CUSAT), Kochi, Kerala. The event has become a significant platform for researchers in southern India to connect, share ideas, and present their work, fostering collaboration within the regional astronomy community. The event was coordinated by Ranjeev Misra (IUCAA), Charles Jose (CUSAT), and Joe Jacob (ICARD, Newman College, Thodupuzha).

(For details, see Khagol 136, April 2025)

Workshop on Optical Astronomy

A three-day workshop on Optical Astronomy was organised by the Department of Physics, St. Thomas College, Ranni, in collaboration with ICARD (Newman College, Thodupuzha) and the Centre for Excellence in Astronomy and Astrophysics, CHRIST (Deemed to be University), Bengaluru, from February 28 to March 02, 2025. The workshop brought together thirty-nine undergraduate students from fifteen colleges, including five participants from outside Kerala. It was coordinated by Sreeja S. Kartha (CHRIST University), Joe Jacob (ICARD), and Ranjeev Misra (IUCAA).

(For details, see Khagol 136, April 2025)

Tensions and Anomalies on the Sky: Quest for New Physics at Cosmological Scales

A three-day workshop titled 'Tensions and Anomalies on the Sky: Quest for New Physics at Cosmological Scales' was organised at the Centre for Theoretical Physics, Jamia Millia Islamia, from March 06 - 08, 2025. The event was supported by the IUCAA Centre for Astronomy Research and Development (ICARD) and the Anusandhan National Research Foundation (ANRF). The workshop brought together forty-seven participants from various institutes and universities across India. The workshop was coordinated by Anjan Ananda Sen (Jamia Millia Islamia) and Anupam Bhardwaj (IUCAA).

(For details, see Khagol 136, April 2025)

Workshop on Stellar Evolution and Pulsation Modelling

A two-day workshop on Stellar Evolution and Pulsation Modelling, organised by the Department of Physics, DDU Gorakhpur University, Uttar Pradesh, in collaboration with IUCAA, Pune, was held from March 24-25, 2025. The workshop provided a platform for students and researchers to explore the field of stellar astrophysics through lectures, discussions, and hands-on training. The workshop was coordinated by Apara Tripathi (DDUGU), Prabhunath Prasad (DDUGU) and Anupam Bhardwaj (IUCAA).

(For details, see Khagol 136, April 2025)

Sheelu Abraham

Automated Detection of Galactic Rings from Sloan Digital Sky Survey Images

Morphological features in galaxies, like spiral arms, bars, rings, tidal tails etc. carry information about their structure, origin and evolution. It is therefore important to catalog and study such features and to correlate them with other basic galaxy properties, the environment in which the galaxies are located and their interactions with other galaxies. The volume of present and future data on galaxies is so large that traditional methods, which involve expert astronomers identifying morphological features through visual inspection, are no longer sufficient. It is therefore necessary to use AI based techniques like machine learning and deep learning for finding morphological structures quickly and efficiently. We report in this study the application of deep learning for finding ring like structures in galaxy images from the Sloan Digital Sky Survey (SDSS) data release DR18. We use a catalog by Buta (2017) of ringed galaxies from the SDSS to train the network, reaching good accuracy and recall, and generate a catalog of 29420 galaxies of which 4855 have ring like structures with prediction confidence exceeding 90 percent. Using a catalog of barred galaxy images identified by Abraham et. al. (2018) using deep learning techniques, we identify a set of 2087 galaxies with bars as well as rings. The catalog should be very useful in understanding the origin of these important morphological structures. As an example of the usefulness of the catalog, we explore the environments and star formation characteristics of ring galaxies in our sample. This work has been done in collaboration with Linn Abraham, Ajit K. Kembhavi, N. S. Philip, A. K. Aniyan,Sudhanshu Barway,Harish Kumar.

Abisa Sinha Adhikary

Fragmentation of Young Massive Clusters in Binary Components: An application of Griddy Gibbs Sampler

Study of the process of hierarchical fragmentation of molecular clouds in Young Massive Clusters to model the Initial Mass Function requires involvement of binary as well as single star components. Components of masses from Gaia EDR3 were estimated using the mass-luminosity relationship and contribution of each to the total system is studied. Stochastic models describing the contribution of each component are developed for binary as well as single stars incorporating the escape mass theory of the assumed pair. Binary masses, fitted to suitable bi-variate distributions are simulated using Griddy Gibbs sampler, an MCMC algorithm. Stellar masses of single stars are simulated from suitable uni-variate distribution. The mass spectrum of the binary as well as single components are then considered together to form the initial mass function. The resulting mass function under opacity limited fragmentation scenario are further investigated at different projected distances from the core to radius where signature of mass segregation is found. This work has been done in collaboration with Ankita Das.

On Analyzing Milkey Way Globular Clusters: Comparing Efficiency Of Dimension Reduction Techniques

Astronomical Data specifically those from Globular Clusters and Young Massive Clusters are usually contaminated with outliers and missing data, detection of which might be very tedious in case the data size is considerably large. Moreover, for skewed multivariate data Principal Component Analysis (PCA) is not an appropriate approach for dimension reduction. The Robust Principal Component Analysis along with the Missing Value Imputation Technique using the MissForest algorithm is applied to a data from the Harris catalog Harris 2010 of globular clusters and the results are demonstrated with some striking features of the clusters.

Faizuddin Ahmed

Electromagnetic Fields in topologically charged traversable wormholes

In this research paper, we focus on analyzing the electromagnetic fields within the framework of a traversable wormhole that incorporates a cosmic string. We then extend our investigation to a traversable wormhole with a global monopole charge, addressing the same problem in this new context. To facilitate our study, we compute the electromagnetic field tensor and derive Maxwell's vacuum field equations, which govern the behavior of the electric and magnetic fields. Using an analytical approach, we obtain solutions for the electromagnetic fields and compare them with the results from conventional Minkowski flat space. Our study demonstrates significant deviations in the electromagnetic fields, and thus, changes the behavior of

electromagnetic waves in the presence of a cosmic string and a global monopole charges within this wormhole background. This work has been done in collaboration with M. G. Kurbah.

Electromagnetic wave propagation in Eddington-inspired Born-Infeld gravity space-time with topological defects

In this study, we focus on examining the characteristics of electromagnetic fields within a curved space-time background under the framework of Eddington-inspired Born-Infeld (EiBI) gravity, in the presence of a global monopole. We derived Maxwell's vacuum field equations in this curved spacetime and obtained a set of linear differential equations for the electric and magnetic fields. After decoupling these equations, we solved for the analytical solutions of both the electric and magnetic fields using special functions. We then extended our analysis to the same EiBI-gravity framework, this time incorporating a cosmic string. Following a similar approach, we derived the first-order differential equations governing the electric and magnetic fields and obtained their analytical solutions using special functions. Our findings demonstrate significant influences of the global monopole, cosmic string, and the Eddington parameters on the behavior of electromagnetic waves in this curved space-time configuration with topological defects, resulting in notable deviations from the Minkowski flat space case. This work has been done in collaboration with M. G. Kurbah.

Musavvir Ali

Curvature inheritance symmetry on M-projectively flat spacetimes

The paper aims to investigate curvature inheritance (CI) symmetry in M-projectively flat spacetimes. It is shown that the CI symmetry in M-projectively flat spacetime is a conformal motion. We have proved that M-projective curvature tensor follows the symmetry inheritance property along a vector field ξ , when spacetime admits the conditions of both CI symmetry and conformal motion or motion along the vector field ξ . Also, we have derived some results for M-projectively flat spacetime with perfect fluid following the Einstein field equations (EFEs) with a cosmological term and admitting the CI symmetry along the vector field ξ . We have shown that an M-projectively flat perfect fluid spacetime obeying the EFEs with a cosmological term and admitting the CI symmetry along a vector field ξ is either a vacuum or satisfies the vacuum-like equation of state. We have also shown that such spacetimes with the energy–momentum tensor of an electromagnetic field distribution do not admit any curvature symmetry of general relativity. Finally, an example of M-projectively flat spacetime has been exhibited. This work has been done in collaboration with Absos Ali Shaikh, Mohammad Salman, and Fusun Ozen Zengin.

A Study of Geodesic (E, F)-Preinvex Functions on Riemannian Manifolds

In this manuscript, we define the (E,F)-invex set, (E,F)-invex functions, and (E,F)-preinvex functions on Euclidean space, i.e., simply vector space. We extend these concepts on the Riemannian manifold. We also detail the fundamental properties of (E,F)-preinvex functions and provide some examples that illustrate the concepts well. We have established a relation between (E,F)-invex and (E,F)-preinvex functions on Riemannian manifolds. We introduce the conditions A and define the (E,F)-proximal sub-gradient. (E,F)-preinvex functions are also used to demonstrate their applicability in optimization problems. In the last, we establish the points of extrema of a nonsmooth (E,F)-preinvex functions on (E,F)-invex subset of the Riemannian manifolds by using the (E,F)-proximal sub-gradient. his work has been done in collaboration with Ehtesham Akhter, and Mohd Bilal.

Gouri Ambika

Recovery of synchronized oscillations on multiplex networks by tuning dynamical time scales

The heterogeneity among interacting dynamical systems or variations in the pattern of their interactions occur naturally in many real complex systems. Often they lead to partially synchronized states like chimeras or oscillation suppressed states like in-homogeneous or homogeneous steady states. In such cases, it is a challenge to get synchronized oscillations in spite of prevailing heterogeneity. In this study, we present a formalism for controlling multi-layer, multi timescale systems and show how synchronized oscillations can be restored by tuning the dynamical time scales between the layers. Specifically, we use the model of a multiplex network, where the first layer of coupled oscillators is multiplexed with an environment layer, that can generate various types of chimera states and suppressed states. We show that by tuning the time

scale mismatch between the layers, we can revive the synchronized oscillations. We analyse the nature of the transition of the system to synchronization from various dynamical states and the role of time scale mismatch and strength of inter layer coupling in this scenario. We also consider a three-layer multiplex system, where two system layers interact with the common environment layer. In this case, we observe anti synchronization and in-homogeneous steady states on the system layers and by tuning their time scale difference with the environment layer, they undergo transition to synchronized oscillations. This work has been done in collaboration with Aiwin T Vadakkan, and Umesh Kumar Verma.

Recurrence analysis of meteorological data from climate zones in India

We present a study on the spatiotemporal pattern underlying the climate dynamics in various locations spread over India, including the Himalayan region, coastal region, and central and north-eastern parts of India. We try to capture the variations in the complexity of their dynamics derived from temperature and relative humidity data from 1948 to 2022. By estimating the recurrence-based measures from the reconstructed phase space dynamics using a sliding window analysis on the data sets, we study the climate variability in different spatial locations. The study brings out the variations in the complexity of the underlying dynamics as well as their heterogeneity across the locations in India. We find almost all locations indicate shifts to more irregular and stochastic dynamics for temperature data around 1972-79 and shifts back to more regular dynamics beyond 2000. These patterns correlate with reported shifts in the climate and Indian Summer Monsoon related to strong and moderate ENSO events and confirm their associated regional variability. This work has been done in collaboration with Joshin John Bejoy.

Tanwi Bandyopadhyay

On the Entropy Corrected Thermal Features of Black Holes

we investigate the thermal properties of black holes using a new class of generalized entropy functions [K. Ourabah, Class. Quantum Grav., 41, 015010 (2024)]. At the fundamental level, these entropic forms are associated with alternative gravitational laws, within an entropic gravity framework. Our investigation revolves around three distinct entropy functions associated with the Yukawa Potential Correction, Non-local Gravity Correction, and Gradient Field Gravity Correction. Through comparative analysis, we study how such entropic constructs impact the thermodynamic behavior of black holes. For each case, we derive the stability thermodynamic conditions associated with the respective entropic constructs. This work has been done in collaboration with Homa Shababi1, and Ujjal Debnath.

The Generalized Second Law Formulated from the Variable Equation of State Parameter

The Generalized Second Law of Thermodynamics (GSLT) is examined in the current work in the backdrop of Friedmann-Robertson-Walker universe. A digression from the standard Bekenstein-Hawking entropy formulation is considered. Two different modified forms of the entropy functions are studied. For the matter component, five well-known parameterizations of the equation of state parameter are taken into consideration. The diagrammatic representations of the rate of change of the entropy functions in the different models are presented. The outcomes suggest that the GSLT is valid in these models for certain choices of the parameters involved.

Prasad Basu

Eccentric orbits in disc-embedded EMRIs : orbital evolution and observability trend in LISA

The purpose of this work is to study the orbital evolution under the combined effect of disc-drag and GW-emission for E/IMRIs endowed with accretion disc. We study the dependence of disc-torque and GW-torque on the orbital-parameters of compact companions. We employ a semirelativistic technique to study E/IMRI-dynamics evolving under most general elliptical-orbits in the equatorial plane and assume natural transonic-disc in the Kerr spaceâ€“time around a supermassive black hole (SMBH). To conduct an accurate investigation, we fix the disc attributes and alter orbital-parameters, mass-ratio of E/IMRIs and spin of SMBH. We notice that high-eccentric orbits with smaller semimajor axis exhibit a more prominent impact of accretion-drag on the companion-dynamics. The magnitude of disc-torque is greater and almost one order higher in retrograde-spins than prograde-spins. We identify the best fitted orbital parameters, which can potentially enhance detectability of accretion-disc

effect on the observed GW-signal. Prioritizing such orbital-configuration, we obtain substantial impact on the dephasing for maximum disc-torque and high signal-to-noise-ratio (SNR) in emitted signals. Employing a threshold-SNR (> 8), we finally identify the detectability trend of those systems in LISA-band. A key aspect of our findings is the ability to constrain the orbital parameters by GW-detection and estimate orbital-ellipticity or other orbital-characteristics by comparing two SNRs. Hence, the study will be important in understanding the orbital-evolution, predicting orbital-configuration, and finding detectability for such gas-rich E/IMRIs. The predictions of E/IMRI formation pathways from ground and more certainly from future space-borne detectors, would also be possible from the likelihood of such eccentric-E/IMRIs in the sky. This work has been done in collaboration with Sangita Chatterjee, Soumen Mondal.

Aru Beri

Identification of the optical counterpart of the fast X-ray transient EP240414a

Fast X-ray transients (FXTs) are extragalactic bursts of X-rays first identified in archival X-ray data, and now routinely discovered by the Einstein Probe in real time, which is continuously surveying the night sky in the soft (0.5â^'4 keV) X-ray regime. In this Letter, we report the discovery of the second optical counterpart (AT2024gsa) to an FXT (EP240414a). EP240414a is located at a projected radial separation of 27 kpc from its likely host galaxy at z=0.4018Â±0.0010. The optical light curve of AT2024gsa displays three distinct components. The initial decay from our first observation is followed by a re-brightening episode, displaying a rapid rise in luminosity to an absolute magnitude of M_r∼-21 after two rest-frame days. While the early optical luminosity and decline rate is similar to luminous fast blue optical transients, the colour temperature of AT2024gsa is distinctly red and we show that the peak flux is inconsistent with a thermal origin. The third component peaks at M_i∼-19 at ≥16 rest-frame days post-FXT, and is compatible with an emerging supernova. We fit the riz-band data with a series of power laws and find that the decaying components are in agreement with gamma-ray burst afterglow models, and that the re-brightening may originate from refreshed shocks. By considering EP240414a in context with all previously reported known-redshift FXT events, we propose that Einstein Probe FXT discoveries may predominantly result from (high-redshift) gamma-ray bursts, and thus appear to be distinct from the previously discovered lower redshift, lower luminosity population of FXTs. This work has been done in collaboration with scientists at the University of Oxford - a large multiwavelength campaign for the follow-up study of Einstein probe discovered FXT.

Broadband study of the Be X-ray binary RX J0520.5-6932 during its outburst in 2024

A new giant outburst of the Be X-ray binary RX J0520.5-6932 was detected and subsequently observed with several space-borne and ground-based instruments. This study presents a comprehensive analysis of the optical and X-ray data, focusing on the spectral and timing characteristics of selected X-ray observations. A joint fit of spectra from simultaneous observations performed by the X-ray telescope (XRT) on the Neil Gehrels Swift Observatory (Swift) and Nuclear Spectroscopic Telescope ARray (NuSTAR) provides broadband parameter constraints, including a cyclotron resonant scattering feature (CRSF) at 32.2(+0.8/-0.7) keV with no significant energy change since 2014, and a weaker Fe line. Independent spectral analyses of observations by the Lobster Eye Imager for Astronomy (LEIA), Einstein Probe (EP), Swift-XRT, and NuSTAR demonstrate the consistency of parameters across different bands. Luminosity variations during the current outburst were tracked. The light curve of the Optical Gravitational Lensing Experiment (OGLE) aligns with the X-ray data in both 2014 and 2024. Spin evolution over 10 years is studied after adding Fermi Gamma-ray Burst Monitor (GBM) data, improving the orbital parameters, with an estimated orbital period of 24.39 days, slightly differing from OGLE data. Despite intrinsic spin-up during outbursts, a spin-down of ∼0.04s over 10.3 years is suggested. For the new outburst, the pulse profiles indicate a complicated energy-dependent shape, with decreases around 15 keV and 25 keV in the pulsed fraction, a first for an extragalactic source. Phase-resolved NuSTAR data indicate variations in parameters such as flux, photon index, and CRSF energy with rotation phase. This work is in collaboration with scientists at MPE where our group has been leading the NICER observations and the analysis.

Piyali Bhar

Properties of the wormhole model in de Rham-Gabadadze-Tolley like massive gravity with specific matter density

In the conventional method of studying wormhole (WH) geometry, traversability requires the presence of exotic matter, which also provides negative gravity effects to keep the wormhole throat open. In de Rham-Gabadadze-Tolley (dRGT) massive gravity theory, we produce two types of WH solutions in our present paper. We obtain the field equations for exact WH solutions by selecting a static and spherically symmetric metric for the background geometry. We derive the WH geometry completely for the two different choices of redshift functions. The obtained WH solutions violate all the energy conditions, including the null energy condition (NEC). Various plots are used to illustrate the behavior of the wormhole for a suitable range of m^2c_1, where m is the graviton mass. It is observed that the photon deflection angle becomes negative for all values of m^2c_1 as a result of the repulsive action of gravity. It is also shown that the repulsive impact of massive gravitons pushes the spacetime geometry so strongly that the asymptotic flatness is affected. The volume integral quantifier (VIQ) is computed to determine the amounts of matter that violate the null energy condition. The complexity factor of the proposed model is also discussed.

Noncommutative black hole in de Rham-Gabadadze-Tolley like massive gravity

We examine the behavior of non-commutative Schwarzschild black holes in the context of massive gravity. According to the investigation, corresponding to a minimal mass, the black hole can have two horizons, one horizon, or no horizon at all. Our results imply the existence of a stable black hole remnant, whose mass can be uniquely calculated in terms of the non-commutative parameter θ and the graviton mass m. Thermodynamic features such as heat capacity and Hawking temperature are studied. We also examine a scalar linear perturbation on the black hole. Quasinormal frequencies are computed via Wentzel–Kramers–Brillouin (WKB) method with Padé improvement. All quasinormal frequencies considered in this work have a negative imaginary part. In the eikonal limit, we investigate the angular velocity and the Lyapunov exponent as a function of $M/\sqrt{\theta}$. Additionally, we explore the black hole's shadow across various model parameters. Our findings indicate that non-commutativity leads to a reduction in the black hole's shadow, with this effect exhibiting a nonlinear relationship. Furthermore, we observe that the inclusion of a massive graviton in the theory results in an increase in the black hole's shadow radius, particularly at greater observer distances. This work has been done in collaboration with Dhruba Jyoti Gogoi,and Supakchai Ponglertsakul.

Debbijoy Bhattacharya

Constraining the Location of the γ-Ray Emission Region in Radio-loud AGN 3C 380

A detailed broadband spectral and temporal study of a radio-loud active galactic nucleus, 3C 380, is carried out using 14.5 yr of Fermi-LAT data, available Swift observations, and data from other observatories, including AstroSat (2020 August). The source exhibited a GeV outburst on 2020 September 5. Given the sparsity of Swift observations, no useful correlations could be established between γ-ray, X-ray, and UV/optical bands. The source is also a part of the Monitoring of Jets in Active Galactic Nuclei with VLBA Experiments survey and has been monitored at 15 GHz for over a decade. The correlation studies show that radio emission lags γ-rays by $\sim$ 150 days. We constrain the location of γ-ray emission by the core shift measurements from the literature and the observed time delays. Using this localization, we constructed and modeled the broadband spectral energy distribution (SED) of the source during its high γ-ray activity states and for the long-term averaged state. The SEDs during the high γ-ray activity states are modeled with two zones: one corresponding to the "steady" or the emission from the source averaged over more than a decade and another corresponding to the "flare" emission. We conclude that the high-energy emission originates within the parsec-scale jet, and moving shocks in the region drive the observed γ-flux variations. This work has been done in collaboration with Sanna Gulati, and P. Sreekumar.

Detection of Faint Sources by the UltraViolet Imaging Telescope Onboard AstroSat Using Poisson Distribution of Background

We present an improved approach for constructing the UV source catalogs using observations from the UltraViolet Imaging Telescope (UVIT) onboard AstroSat, by considering the Poisson distribution of the

UV background. The method is tested extensively using fields that are not crowded, the Small Magellanic Cloud and M31 (Field 13). The results are compared with previous studies that used UVIT observations. This approach is successful in detecting fainter sources and produces a large number of new sources (∼15% -92% more). Most of the newly discovered UV sources fall in the faint end of the source distribution (m $\geq$ 22). The counterparts at other wavelengths are identified for most sources. This approach is more efficient for source detection and provides an opportunity to explore new classes of UV sources. This work has been done in collaboration with B. Ananthamoorthy, P. Sreekumar, and Swathi B.

Naseer I. Bhat

Insights into the long term flaring events of Blazar PKS 0805-07: A Multiwavelength Analysis over the 2009-2023 period

We conducted a comprehensive temporal and spectral study of the FSRQ PKS 0805-07 by using the broadband observations from the Fermi-LAT and Swift-XRT/UVOT instruments over the period MJD 54684-60264. The 3-day binned γ-ray light curve during the active state revealed eleven distinct peak structures with the maximum integral flux ($E > 100$ MeV) reached $(1.56 \pm 0.16) \times 10^{-6}$ photons cm^{-2} s^{-1} on MJD 59904.5. The shortest observed γ-ray variability was 2.80 ± 0.77 days. A correlation analysis between the γ-ray spectral index and flux indicated the typical trend of hardening when the source is brighter, commonly observed in blazars. We identified a lag of 121 (+27.21, −3.51) days in the spectral index relative to the flux, within the time interval MJD 59582 to 60112. The Anderson-Darling test and histogram-fit rejected the normality of the γ-ray flux distribution and instead suggest a log-normal distribution. To gain insight into the underlying physical processes, we extracted broadband spectra from different time periods in the light curve. The spectral energy distribution during various flux states were well-reproduced using synchrotron, synchrotron-self-Compton, and external-Compton emissions from a broken power-law electron distribution. The seed photons required for the external Compton process are from IR region. A comparison of the best-fit physical parameters indicated that the variations in different flux states were primarily associated with an increase in the bulk Lorentz factor and magnetic field from low to high flux states. This work has been done in collaboration with Sikandar Akbar, Zahir Shah, and Ranjeev Misra.

Study of Multiwavelength variability, Emission Mechanism and Quasi-periodic oscillation for transition Blazar S5 1803+784

This work presents the results of a multi-epoch observational study of the blazar S5 1803+784, carried out from 2019 to 2023. The analysis is based on simultaneous data obtained from the Swift/UVOT/XRT, ASAS-SN, and Fermi-LAT instruments. A historically high γ-ray flux observed for this source on March 2022 $(2.26 \pm 0.062) \times 10^{-6}$ ph cm^{-2} s^{-1}. This study investigates the γ-ray emission from a blazar, revealing a dynamic light curve with four distinct flux states: quiescent and high-flux by using the Bayesian Blocks (BB) algorithm. A potential transient quasi-periodic signal with an oscillation timescale of ∼411 days was identified, showing a local significance level surpassing 99.7% from the Lomb-Scargle Periodogram (LSP) and Damped Random Walk (DRW) analysis and exceeds 99.5% from the Weighted Wavelet Z-Transform (WWZ) analysis. The observed QPO was confirmed through an autoregressive process (AR(1)), with a significance level exceeding 99%, suggesting a potential physical mechanism for such oscillations involves a helical motion of a magnetic plasma blob within the relativistic jet. Log parabola modelling of the γ-ray spectrum revealed a photon index (α_γ) variation of 1.65±0.41 to 2.48±0.09 with a steepening slope, potentially indicative of particle cooling, changes in radiative processes, or modifications in the physical parameters. The α_γ of 2.48 ± 0.09 may hint at an evolutionary transition state from BL Lac to FSRQ. A comparative analysis of variability across different energy bands reveals that Optical/UV and GeV emissions display greater variability compared to X-rays. Broadband SED modelling shows that within a one-zone leptonic framework, the SSC model accurately reproduces flux states without external Compton contributions, highlighting magnetic fields crucial role. This work has been done in collaboration with Javaid Tantry, Ajay Sharma, Zahir Shah, and Debanjan Bose.

Subhra Bhattacharya

Some Classes of Interacting Two-Fluid Model of the Expanding Universe

We consider interacting dark matter-dark energy models arising out of a general interaction term

$Q = f(\rho_m, \rho_d, \dot{\rho}_m, \dot{\rho}_d)$. Here f is a functional relation connecting the energy densities ρ_m and ρ_d and their derivatives w.r.t. time t. In our model we consider two interacting barotropic fluid with constant equation of state ω_m and ω_d. By considering a dynamical interaction between them we trace out the cosmological evolution dynamics of the universe. We analytically solve the model by considering a constant ratio between the two fluids and then track the corresponding analytical results using observational data from the baryon acoustic oscillation measurements, Type Ia supernovae measurements and the local Hubble constant measurements. From this general setting we introduce three different models and nine different interaction function. Our final aim is to set up a comparative analysis of the various class of models under the different interaction function using common theoretical and numerical analysis.

Dynamics of Dissipative Gravitational Collapse in the Morris-Thorne Wormhole Metric: One Scenario - Several Outcomes

We consider the dynamical Morris-Thorne metric with radiating heat flow. By matching the interior Morris-Thorne metric with an exterior Vaidya metric we trace out the collapse solutions for the corresponding spherically symmetric inhomogeneous distribution of matter. The solutions obtained are broadly of four different types, giving different end state dynamics. Corresponding to three of the solutions we elaborate the collapsing dynamics of the Morris-Thorne type evolving wormhole. We show that for all those cases where collapse upto zero proper volume is obtained in finite time, the ensuing singularity is always a black hole type. However our solutions can also show other end states, like oscillating wormhole-black hole pair or infinite time contracting universe or a conformal past matter dominated universe. In all the cases we have worked out the background dynamics and physics of the solution. All our solutions are illustrated with appropriate graphical descriptions. This work has been done in collaboration with Subhasis Nalui.

Ritabrata Biswas

Isolated compact star $RXJ-1856.5-3754$ in $f(R,T)$ modified gravity in Tolman-Kuchowicz spacetime

Studies in dark energy accretion reveal that the repulsive force of exotic matter decreases the effective radius of accretion disc. Matter beyond this short radius are likely to be thrown out due to enormous wind speed. Addition of viscosity along with the negative pressure of dark energy enhances this nature of weakening of dark energy accretion and the size of the disc becomes more tiny. This happens due to the strong wind outflow. In this article, we study the properties of both the accretion and the wind via detailed variations of the density of modified Chaplygin gas flow. We compare our results of (non) viscous, (non) rotating, adiabatic and modified Chaplygin gas cases graphically. Nature of accreting branch's density is studied thoroughly. A sharp fall in accretion density, i.e., formation of a threshold fall is observed to occur. For the first time in literature, effect of dark energy accretion on both the accretion and wind branches are analysed. This work has been done in collaboration with Mayukh Bandyopadhyay.

Cosmology in $f(R,T)$ modified gravity : unified dark matter and dark energy model constrained by current observations

The proposed cosmological model deals with modified Chaplygin gas (MCG) in $f(R,T) = R + \xi(T)$ gravity, where R is the Ricci Scalar and T is the trace of energy-momentum tensor. The function $\xi(T)$ is chosen as the linear combination of power law and logarithmic form under flat Friedmann-Lemaitre-Robertson-Walker space-time. The model is compatible with current observational data (Pantheon Type Ia Supernova) and confronts the deceleration and state parameters effectively. The model can predict the Big Rip in future infinity and can also tackle the difficulties related to the fine-tuning and the coincidence problem practically. Further, we have numerically solved the modified Friedmann equations in $f(R,T)$ gravity and also performed a Markov Chain Monte Carlo analysis to obtain the best fit parameters of this current cosmological model. These best parameters are then used to compute the cosmographic parameters, i.e., the deceleration parameter, the jerk parameter and the snap parameter. Significantly, the cosmographic test has given valuable insights into the dynamics of the current cosmological model and also enriched us to understand about the cosmic evolution of the accelerated Universe. Additionally, the Statefinder diagnostics and Om diagnostics have provided deeper insights into the dynamics of the cosmic expansion and also provided information to distinguish between both the cosmological frameworks. Furthermore, these tests also reveal that at late times, the current model goes beyond the phantom region. Again, the Akaike

Information Criterion (AIC) and Bayesian Information Criterion (BIC) have provided enough support for the current model under consideration, indicating that the present model exhibits a plausible explanation. However, the ΛCDM model has emerged with the lowest AIC value which suggests its relatively superior fit compared to the current model. Finally, our current model aligns well with several recent observations and unveils various intriguing features about the late time accelerated Universe. This work has been done in collaboration with Mayukh Bandyopadhyay.

Mridusmita Buragohain

C−D_{oop} vibrational modes in PAHs Investigating C−D out-of-plane vibrational modes in PAHs as a tool to study interstellar deuterium-containing PAHs

Previous as well as recent observations by *ISO*, *Spitzer*, *AKARI*, *SOFIA*, *JWST* etc. have revealed various characteristics of mid-infrared emission bands between 3−20 μm. Subsequently, several forms of organics including Polycylic Aromatic Hydrocarbons (PAHs)/PAH-like molecules are proposed as carriers for these bands. Deuterated PAH (PAD) is one such substituted PAH, which is proposed as a potential candidate carrier for weak emission bands at 4.4 and 4.65 μm, detected towards few astronomical targets and are characteristics of aromatic and aliphatic C−D stretching modes in a PAD molecule, respectively. However, the 4.4 μm band is not widely detected. In order to validate PADs as carriers for mid-infrared emission bands, an additional alternative tool is crucial. If PAHs are deuterated, they should also possess an inherent signature from the C−D out-of-plane (C−D_{oop}) vibrations, which are at the longer wavelength side. In this report, features due to C−D_{oop} modes in PAHs bearing a single to multiple deuterium atoms are reported by performing quantum-chemical calculations. This paper reports that some of the C−D_{oop} vibrations appear at the 14−19 μm range. Also, the strength of C−D_{oop} modes is not proportional to the D/H ratio in PAHs. In addition, a moderate change in the spectra of deuterated PAHs is observed from that of the undeuterated counterparts, as deuteration would alternate the adjacency class of the C-H bonds and the symmetry of the molecule. We discuss the efficiency and usefulness of these bands to constrain the form of PAHs emitting mid-infrared emission bands. This work has been done in collaboration with Takashi Onaka, Amit Pathak, et all.

Chandrachur Chakraborty

The Lunar Gravitational-wave Antenna: Mission Studies and Science Case

The Lunar Gravitational-wave Antenna (LGWA) is a proposed array of next- generation inertial sensors to monitor the response of the Moon to gravitational waves (GWs). Given the size of the Moon and the expected noise produced by the lunar seismic background, the LGWA would be able to observe GWs from about 1 mHz to 1 Hz. This would make the LGWA the missing link between space-borne detectors like LISA with peak sensitivities around a few millihertz and proposed future terrestrial detectors like Einstein Telescope or Cosmic Explorer. In this article, we provide a first comprehensive analysis of the LGWA science case including its multi-messenger aspects and lunar science with LGWA data. We also describe the scientific analyses of the Moon required to plan the LGWA mission. This work has been done in collaboration with Parameswaran Ajith, Pau Amaro Seoane, Manuel Arca Sedda, Riccardo Arcodia, Francesca Badaracco et, al.

Thin Inner Accretion Disk around a Kerr-Taub-NUT black hole

The accreting collapsed object GRO J1655-40 could contain the gravitomagnetic monopole (GMM), and it was shown to be better described by the Kerr-Taub-NUT (KTN) spacetime instead of the Kerr spacetime. The warped accretion disk has also been observed for the same collapsed object. Motivated by these, we study a tilted thin inner accretion disk around a KTN black hole. Such a tilting could have a significant effect on the X-ray spectral and timing features via the Lense-Thirring effect. Taking into account the contribution from the inner accretion disk for the KTN black hole, here we calculate the radial profile of a tilt angle. Depending on the numerical values of the viscosity of the accreting material and Kerr parameter, GMM tends the angular momentum of the disk to align along the black holes spin axis, or to make it more tilted. Our solution for the radial profile of the tilted disk around a KTN black hole could be useful to probe the strong gravity regime, and could also give indirect evidence for the existence of GMM in nature. This work has been done in collaboration with G. Sen, , S. Bhattacharyya, D. Maity, S. Chakrabarti, and S. Das.

Subenoy Chakraborty

Traversable Wormholes and their shadows in 4D Einstein-Gauss-Bonnet Gravity: An analytic description

Einstein-Gauss-Bonnet gravity (EGB) in 4D started its journey in 2020, after a regularization on $D \to 4$ limit of EGB gravity considering a rescaled GB coupling constant as $\frac{\alpha}{(D-4)}$ and taking the limit $D \to 4$ by Glavan and Lin. As a result, the regularized 4D gravity theory have non trivial gravitational dynamics. The present work is an attempt to obtain solutions of 4D EGB theory in the background of static spherically symmetric space-time and it has been examined whether they correspond to any possible traversable Wormhole (WH). For matter field, isotropic/ anisotropic fluid and various possible equation of state are considered. Embedding diagrams are analyzed and energy conditions are examined for the WH solutions. Finally, feasible WH shadows have been determined in EGB theory. This work has been done in collaboration with Madhukrishna Chakraborty.

Implications of Raychaudhuri equation and geodesic focusing in interacting two fluid systems

The present work analyses Raychaudhuri equation (RE) in Einstein gravity for two interacting fluids . Focusing theorem, a consequence of RE is directly related to the singularity theorems of Penrose and Hawking. In the present work, the signature of the Raychaudhuri scalar or convergence scalar has been examined for two types of interaction forms namely, (i) $Q = H(\alpha\rho_1 + \beta\rho_2)$ (linear) and (ii) $Q = \frac{H\xi\rho_1\rho_2}{\alpha\rho_1 + \beta\rho_2}$ (non-linear). Finally, the phenomena of focusing of a congruence of geodesics and possible avoidance of singularity have been discussed based on the nature of the two fluids and the interaction term operating between them.This work has been done in collaboration with Madhukrishna Chakraborty.

Nand K. Chakradhari

Weak secondary cyclotron line in eclipsing high-mass X-ray binary Cen X-3

We report the time-resolved spectroscopy results from two observations of Centaurus X-3, over one binary orbit with *AstroSat* and two binary orbits with *Nuclear Spectroscopic Telescope Array (NuSTAR). NuSTAR* covered two intensity states where the light curve showed transition in count rate from first to second binary orbit by a factor of ~ 3. A phenomenological model comprising of partially absorbed power law with smoothed high energy cutoff, cyclotron absorption ~ 24 and 6.4 keV iron emission gave good fit for *AstroSat* observation. *NuSTAR* spectra required two additional emission components, a broad one ~ 5.7 keV and a narrow one ~ 6.9 keV. A weak secondary absorption feature at ~ 11.6 and ~ 14.5 keV was seen in the residuals of the spectral fit for *AstroSat* and *NuSTAR* data, respectively. The secondary absorption energy showed no correlation with the cutoff energy. Its strength varied within 0.1–0.6 keV with its width ~ 1.6 keV. Its energy and optical depth showed linear positive correlation with the fundamental cyclotron line energy and depth, respectively. The cyclotron line energy showed anticorrelation to flux described by a power law with negative index and the secondary absorption also showed similar trend to flux. Depth of secondary absorption was ~ 45 per cent and centroid energy was ~ 54 per cent of fundamental. Depth and energy ratio of secondary to fundamental lied within 2σ deviation from 0.5. We suggest this secondary absorption to be a redshifted dipolar cyclotron resonance feature exhibiting sub-harmonic behaviour. This is a collaborative work of Pravat Dangal, Ranjeev Misra, and Yashpal Bhulla.

Search for merger ejecta emission from late time radio observations of short GRBs using GMRT

In some cases, the merger of two neutron stars can produce a rapidly rotating and highly magnetized millisecond magnetar. A significant proportion of the rotational energy deposited to the emerging ejecta can produce a late-time radio brightening from interacting with the ambient medium. Detection of this late-time radio emission from short GRBs can have profound implications for understanding the physics of the progenitor. We report the radio observations of five short GRBs - 050709, 061210, 100625A, 140903A, and 160821B using the legacy Giant Metrewave Radio Telescope (GMRT) at 1250, 610, and 325 MHz frequencies and the upgraded-GMRT (uGMRT) at band 5 (1050-1450 MHz) and band 4 (550-900 MHz) after ∼2-11 yr from the time of the burst. The GMRT observations at low frequencies are particularly important to detect the signature of merger ejecta emission at the peak. These observations are the most delayed searches associated with some GRBs for any late-time low-frequency emission. We find no evidence for such an emission. We find that none of these

GRBs is consistent with maximally rotating magnetar with a rotational energy of $\sim 10^{53}$ erg. However, magnetars with lower rotational energies cannot be completely ruled out. Despite the non-detection, our study underscores the power of radio observations in the search for magnetar signatures associated with short GRBs. However, only future radio observatories may be able to detect these signatures or put more stringent constraints on the model. This is a collaborative work of Ankur Ghosh, C. S. Vaishnava, L. Resmi, Kuntal Misra, K. G. Arun,and Amitesh Omar.

Hum Chand

Weak emission-line quasars: a new clue from their optical variability

Weak emission-line quasars (WLQs) are an enigmatic subclass of the QSO population, as their optical/UV spectra are marked by abnormally weak (or absent) emission lines. To obtain much-needed additional clues to the origin of this and other known peculiarities of WLQs, we have determined the 'ensemble' optical variability characteristics for a large, well-defined sample of 76 radio-quiet WLQs and also for a matched control sample comprising 603 normal radio-quiet QSOs. This analysis was done using their light curves recorded in the g and r bands, under the Zwicky Transient Facility survey during 2018-2024, with a typical cadence of 3 d. We find that, compared to normal QSOs, WLQs exhibit systematically milder optical variability on month/year-like time-scales (by a factor of $\sim$1.76 $\pm$ 0.05 in amplitude). We have independently verified this by carrying out an equivalent analysis of the V-band light curves acquired under the Catalina Real-Time Transient Survey during 2007-2014, with a typical cadence of 10 d. This new observational differentiator between WLQs and normal QSOs may provide clues to understanding the intriguing nature of WLQs. It is proposed that the clumpiness of the torus material flowing into the central engine may play a key role in explaining the observed differences between the WLQs and normal QSOs. This work has been done in collaboration with Kumar Ritish, Krishna Gopal, and Negi Vibhore.

Star formation in neutral hydrogen gas reservoirs at cosmic noon

We aim to constrain the average star formation associated with neutral hydrogen gas reservoirs at cosmic noon. Using a unprecedented sample of 1716 high column density Damped Ly-α absorbers (DLAs) from the Sloan Digital Sky Survey with $\log(N(\mathrm{H\ I})\ /\ \mathrm{cm}^{-2}) \geq 21$, we generated the average Ly-α emission spectrum associated to DLAs, free from emission from the background quasar. We measured Lyα emission at $> 5.8\sigma$ level with luminosity $8.95 \pm 1.54 \times 10^{40}$ erg s^{-1} (corresponding to about 0.02 L* at $z \sim$ 2-3) in systems with average $\log(N(\mathrm{H\ I})\ /\ cm^{-2}) \approx 21.2$ and at median redshift of $z \sim 2.64$. The peak of the Lyα emission is apparently redshifted by $\sim$300 km s^{-1} relative to the absorption redshift, which is seemingly due to suppression of blue Ly-α photons by radiative transfer through expanding gas. We infer that DLAs form stars with an average rate of $(0.08 \pm 0.01)/\mathrm{f_{esc}}\ \mathrm{M_\odot\ yr^{-1}}$, i.e, $\approx (0.54 \pm 0.09)\mathrm{M_\odot\ yr^{-1}}$ for a typical escape fraction, $\mathrm{f_{esc}} = 0.15$, of Lyman-α emitting galaxies. DLA galaxies follows the star formation main sequence of star-forming galaxies at high redshift, suggesting that the DLA population is dominated by the lower mass end of Lyman-α emitting galaxies. This work has been done in collaboration with Dharender, Ravi Joshi , Michele Fumagalli, Pasquier Noterdaeme , and Ho Luis C.

Suresh Chandra

Methanimine in cool cosmic objects using accurate collisional rate coefficients

Accurate collisional rate coefficients for collisional transitions between 15 rotational levels of methanimine, colliding with p-H_2 molecule, are available. Methanimine is a planar, asymmetric top molecule having electric dipole moment with components μ_a = 1.3396 Debye and μ_b = 1.4461 Debye, and thus, producing both a and b type spectral lines of nearly equal intensities. Therefore, all the rotational levels need to be considered together. Between 15 rotational levels, 105 collisional transitions are considered in an investigation by others. We have discussed that each level is not connected with all others through the collisions, and therefore, there should be 77 instead of 105 collisional transitions between 15 levels of methanimine. With availability of accurate collisional rate coefficients, it is worth to perform the Sobolev analysis of methanimine. We have found three weak MASER transitions, $1_{10} - 1_{11}$, $2_{11} - 2_{12}$, and $3_{12} - 3_{13}$, and one transition $1_{11} - 2_{02}$, showing anomalous absorption. These four lines may play important role for the methanimine. This work has been done in collaboration with M. K. Sharma .

MASER and dasar lines of SiCSi using accurate rate coefficients

The molecules with Si-C bonds (SiCSi, SiC_2, and SiC) are thought to play a critical role in the formation of SiC dust around carbon-rich stars. Precise collision rate coefficients for rotational transitions in disilicon carbide due to collisions with para-H_2 ($j = 0$) are now available. Thus, this work focuses on the study of the Maser and Dasar lines of disilicon carbide using accurate collisional rate coefficients. For available collision rate coefficients for 31 levels, we have considered kinetic temperatures up to 30 K. The molecule SiCSI is an asymmetric *b*-type with only para levels due to the zero nuclear spin of both the carbon and silicon atoms of the carbon and silicon atoms. We solved a set of 31 statistical equilibrium equations coupled with 62 radiative transfer equations (Sobolev analysis) using accurate collision rate coefficients. Two of 62 radiative transitions exhibited Maser action, while five were identified as dasar lines. The results are compared with those obtained using scaled collision rate coefficients. Significant differences are found, highlighting the importance of using accurate collision coefficients. This work has been done in collaboration with Otoniel Denis-Alpizar.

Suchetana Chatterjee

Spectral Energy Distribution Modeling of Broad Emission Line Quasars: From X-ray to Radio Wavelengths

We study the differences in physical properties of quasar-host galaxies using an optically selected sample of radio loud (RL) and radio quiet (RQ) quasars (in the redshift range $0.15 \leq z \leq 1.9$) which we have further cross-matched with the VLA-FIRST survey catalog. The sources in our sample have broad Hβ and MgII emission lines (1000 km/s < FWHM < 15000 km/s) with a subsample of high broad line quasars (FWHM > 15000 km/s). We construct the broadband spectral energy distribution (SED) of our broad line quasars using multi-wavelength archival data and targeted observations with the *AstroSat* telescope. We use the state-of-the-art SED modeling code `CIGALE v2022.0` to model the SEDs and determine the best-fit physical parameters of the quasar host galaxies namely their star-formation rate (SFR), main-sequence stellar mass, luminosity absorbed by dust, e-folding time and stellar population age. We find that the emission from the host galaxy of our sources is between 20%-35% of the total luminosity, as they are mostly dominated by the central quasars. Using the best-fit estimates, we reconstruct the optical spectra of our quasars which show remarkable agreement in reproducing the observed SDSS spectra of the same sources. We plot the main-sequence relation for our quasars and note that they are significantly away from the main sequence of star-forming galaxies. Further, the main sequence relation shows a bimodality for our RL quasars indicating populations segregated by Eddington ratios. We conclude that RL quasars in our sample with lower Eddington ratios tend to have substantially lower star-formation rates for similar stellar mass. Our analyses, thus, provide a completely independent route in studying the host galaxies of quasars and addressing the radio dichotomy problem from the host galaxy perspective. This work has been done in collaboration with Avinanda Chakraborty, Maitreya Kundu, Swayamtrupta Panda, Arijit Sar, Sandra Jaison, and Ritaban Chatterjee.

Asis Kumar Chattopadhyay

Investigation of the effect of bars on the properties of spiral galaxies: a multivariate statistical

Subjective classification of spiral galaxies is not sufficient for studying the effect of bars on their physical characteristics. In reality the problem is to comprehend the complex correlations in a multivariate parametric space. Multivariate tools are the best ones for understanding this complex correlation. In this work an objective classification of a large set (26,089) of spiral galaxies was compiled as a value added galaxy catalogue from sdss DR 15 virtual data archive. Initially for dimensionality reduction, Independent Component Analysis is performed to determine a set of Independent Components that are linear combinations of 48 observed features (namely ionized lines, Lick indices, photometric and morphological properties). Subsequently a K-means cluster analysis is carried out on the basis of the 14 best chosen Independent Components to obtain 12 distinct homogeneous groups of spiral galaxies. Amongst these, 3 groups are the oldest ones, while 5 groups fall in the medium aged category , 2 groups consist of only unbarred spirals, 1 group is the youngest one and the remaining one is an outlier. In many groups there are clear indication of recurrent bar formation phenomena which is consistent with few previous simulation works. In order to study the robustness of the clusters with respect to the method of clustering, a second method

of clustering by Gaussian Mixture Modeling Method (GMMBC) is applied. This work has been done in collaboration with Prasenjit Banerjee, and Tanuka Chattopadhyay.

Data based investigation on galaxy formation and evolution theory through statistical techniques

The present work deals with a large data set of star-forming as well as quiescent galaxies at red shifts ranging from 0 to 4 ($0 \leq z \leq 4$). The present selected catalogues of objects have been compiled from the NEWFIRM Medium-Band Survey (NMBS). We have concatenated both the catalogues AEGIS and COSMOS, present in NMBS, one after another to form a master catalogue. Several derivable parameters were present in the catalogue, but we have limited our choice to the observable as well as the physical parameters of the galaxies. In this paper, we have studied the evolutionary pattern of the galaxies by dividing them into various groups according to red shift, and observing the distributional pattern of those groups. Later, the evolutionary pattern of the galaxies is investigated by examining the size-mass relationship corresponding to these groups and comparing the level of dependence of the parameters under study. In order to perform a proper analysis of the data for the above-mentioned objectives, we have used statistical techniques like multiple testing, the Shapiro–Wilk test, independent component analysis, multivariate outlier detection, multivariate kernel density estimation, and kernel regularized least squares method. Two noble findings that have been observed in this work are (a) The galaxy parameters with high red shifts ($z > 3.5$) follow a multivariate Gaussian distribution, helping us to infer that high red shift ($z > 3.5$) galaxy parameters show more randomness compared to other galaxies with $z<3.5$. (b) There is a deviation from the linearity of the covariates in very high-redshift galaxies ($z > 3.5$) for modeling log mass as a response variable. The same is also observed with the half-life radius as the response variable, although there exists a linear relationship between the mass and the effective radius of the galaxy. These observations may be treated as new findings of the present study.This Study has been done in collaboration with Prasenjit Banerjee, Tanuka Chattopadhyay.

Pradip Kumar Chattopadhyay

Effect of baryon number density (n) on the maximum mass and stability of strange stars

A new class of relativistic solutions of Einstein field equations for an anisotropic strange star admitting the Vaidya-Tikekar type metric potential in the framework of MIT bag model equation of state of the strange matter, $p_r = \frac{1}{3}(\rho - 4B)$, where B is termed as bag constant, is presented. In order to integrate the quark core hypothesis and provide an explanation for a physically feasible stellar model, we have examined the baryon number dependent B (n) via an extreme Wood-Saxon, like parameterisation. The energy per baryon (E_B) has been calculated to restrict B (n) within the stable window, i.e., $E_B < 930.4\ MeV$ (^{56}Fe). This study investigates the baryon number density (n) induced phase transition between hadrons and quarks inside a stellar configuration. Interestingly, the nature of the variation of E_B vs. n, shows that for $n \geq 1.1\ fm^{-3}$ the energy per baryon approaches a constant value. We choose $n = 0.6\ fm^{-3}$, $B = 66.32\ MeV/fm^3$ within the stipulated restrictions and consider 4U 1608-52 as a strange star candidate. We find that all the characteristic properties are well satisfied within the stellar interior for the choice of parameters. The numerical solution of the TOV equations yields a maximum mass of strange quark stars of 2.01 $M_\odot$ and a corresponding radius of 10.96 Km. Proposed model meets the necessary energy conditions and also stability criteria, confirming its viability as a realistic stellar model within the parameter space used. This work has been done in collaboration with A. Nag, D. Bhattacharjee,and K. B. Goswami.

Charged gravastar model in Rastall theory of gravity

Gravastars are considered as exotic compact objects, may be found at the end of gravitational collapse of massive stars, to resolve the complexities of black holes. In this paper, we analyse the role of charge on the possible formation of an isotropic spherically symmetric gravastar configuration in the framework of Rastall gravity. Gravastar contains three distinct layers *viz.* (i) Interior region characterised by the equation of state, $p = -\rho$, which defines the repulsive outward pressure in the radial direction at all points on the thin shell, (ii) Thin shell contains an ultra-relativistic stiff fluid, which is denoted by the equation of state $p = \rho$ following Zel'dovich's criteria for a cold baryonic universe, and can withstand the repulsive pressure exerted by the interior

region, and (iii) Exterior region which is the vacuum space-time represented by the Reissner-Nordström solution. Following above specifications, we construct and analyse charged gravastar model in the framework of Rastall gravity, which represents several salient features. The basic physical attributes, *viz.* proper length, energy, entropy and equation of state parameter of the shell are investigated. In this model, it is interesting to note that for a large radius of the hypersurface (R), the equation of state parameter of the thin shell corresponds to a dark energy equation of state with $\mathcal{W}(R) \to -1$. However, for small value of R, $\mathcal{W}(R) \to 0$, defines dust shell. The stability of the model is ensured through the study of gravitational surface redshift and maximisation of shell entropy within the framework of Rastall theory of gravity. This work has been done in collaboration with D. Bhattacharjee.

Surajit Chattopadhyay

Holographic connection of $f(G)$ gravity through Barrow and a generalized version of holographic dark fluid

In the study presented in this work, we use the holographic principle taking into account the Barrow entropy rather than the conventional Bekensteinâ€“Hawking one to develop a holographic model for dark energy in the $f(G)$ gravity. The former results from the attempt to include quantum gravitational effects into the cosmological framework and, in accordance with the gravityâ€“thermodynamic conjecture, into black hole physics. To investigate the cosmological implications of our model for $f(G)$ modified gravity, we discuss the cosmic implementation of the most generalised type of holographic dark energy, called Nojiri-Odintsov holographic dark energy (NO-HDE), and a particular example of it, called Barrow holographic dark energy. This is accomplished by adding to the $f(G)$ model a well-known power law form of the scale factor $a(t)$ and the Holographic dark energy. It is found that the reconstructed $f(G)$ satisfies a necessary condition for a realistic modified gravity model. Additionally, the reconstruction models are examined in the four energy scenarios. Lastly, the relationship to observational boundaries is examined, and the reconstructed EoS parameter is verified to fall within the constraints-determined in the literature by utilising observational data sets from BAO, SNLS3, and $Planck + WMAP9 + WiggleZ$.

Thermodynamics of the most generalized form of Holographic Dark Energy and some particular cases with Corrected Entropies

A four-parameter generalized entropy has recently been developed based on the generalized cut-off of holographic dark energy (HDE) formalism. It reduces to various known entropies for appropriate parameter limits, as shown in recent studies by Odintsov and others. In the current work, we investigate the evolution of the universe in its early and late phases within the framework of entropic cosmology, where the entropic energy density functions are reconstructed within the framework of the equivalence of holographic dark energy and four-parameter generalized entropy ($\mathcal{S}_g$). Also, we examined different entropic dark energy models in this regard, including the generalized holographic dark energy with Nojiri-Odintsov(NO) cut-off, the Barrow entropic HDE (BHDE), and the Tsallis entropic HDE (THDE) as IR cut-off, all of three particular cases of the most generalized four parameter entropic holographic dark energy. Inspired by the works of Nojiri and others, our current work reports a study on cosmological parameters and thermodynamics with entropy corrections to cosmological horizon entropy as well as black hole entropy with a highly generalized viscous coupled holographic dark fluid along with its particular cases. This work is carried out in collaboration with Sanghati Saha, Ertan G¨udekli and Gizem Dilara A¸can Yildiz.

Bhag Chand Chauhan

TeV scale Leptogenesis with triplet Fermion in Connection to Muon $g-2$

We propose an extension of the minimal scotogenic model with a triplet fermion and a singlet scalar. An imposed $Z_4 \times Z_2$ symmetry allows only diagonal Yukawa couplings among different generations of SM leptons and right-handed singlet neutrinos. The Yukawa coupling of the triplet fermion with the inert doublet positively contributes to the muon anomalous magnetic moment. The imposed $Z_4 \times Z_2$ symmetry forbids the conventional leptogenesis from the lightest right-handed neutrino decay. A net lepton asymmetry can be generated in the muonic sector from N_2 and triplet fermion decay through resonant leptogenesis scenario. The Yukawa coupling of triplet plays significant role both in leptogenesis and in the anomalous magnetic moment of the muon. We show a viable parameter space for TeV scale leptogenesis while explaining the Fermi lab

results. The inert scalar is the dark matter candidate in this model. The Muon $(g-2)$ and dark matter both favor the same parameter space for mass of the dark matter and the triplet fermion. This work has been done in collaboration with Simran Arora,and Devabrat Mahanta.

IKS: In the Roots of Modern Science

Today nobody would disagree with the fact that the Europe was the epicentre of the activities related to the origin and evolution of modern science. In fact, during the 15th and 16th Century the people started questioning the authority of Church about the established false paradigm of natural laws. Several scholars and philosophers dared, and pave the way to the scientific revolution in Europe. Definitely during that period most part of the Indian subcontinent was repressed and struggling with the invaders and looters. Over the passage of time India drown into the regime of severe poverty and deep ignorance. The slavery of about thousand years led Indian minds and knowledge tradition into the oblivion. As such, in the modern days it is nearly impossible to believe that India could be the cradle of science, technology and unimaginable human knowledge system during ancient times. It is corroborated by several noted scholars that India is the root source of a large number of scientific inventions and discoveries that have otherwise credited by the Europeans. These concepts have been the foundation stones for the modern scientific edifice. Despite the fact, the Indian contribution has been put under the rug of Eurocentric bias. Historians and scholars corroborate that India has been a phenomenal source of fascination and a great material wealth on this planet for centuries. Contribution of the ancient Indians in art, science, literature, and architecture including all spheres of human life is remarkable and we all must be proud of it. In this work, the Indian Knowledge System (IKS) at the foundation of modern scientific thought especially in the fields of science, mathematics and astronomy have been discussed.

Mamta Dahiya

W- mass and muon g-2 in an inert 2HDM extended by a singlet complex scalar

The deviations of the recent measurements of the muon magnetic moment and the W-boson mass from their SM predictions hint to new physics beyond the SM. In this article, we address the observed discrepancies in the W-boson mass and muon anomalous magnetic moment in the Inert Two Higgs Doublet Model extended by a complex scalar field singlet under the SM gauge group. The model is constrained from the existing Large Electron Positron Collider (LEP) data and the measurements of partial decay widths to gauge bosons at LHC. It is shown that a large subset of the constrained parameter space of the model can accommodate both the experimentally measured as well as SM global fit value of W-boson mass while simultaneously explaining the observed muon g-2 anomaly. This work has been done in collaboration with Hrishabh Bharadwaj, Sukanta Dutta and Ashok Goyal.

Himadri Sekhar Das

Turbulence and Magnetic Field Alignment in Small Molecular Clouds: the Role of Cloud Size, Mass and Density

In this study, we investigate the relationship between turbulence (ΔV) and different physical parameters in 22 isolated small molecular clouds and their cores, extending the analysis to a hierarchical scenario from core-to-cloud. Using ^{12}CO linewidth as a tracer of turbulence, we find that ΔV correlates with both cloud size and mass, following $\propto (L_{cl})^{0.30\pm0.04}$ and $\propto (M_{cl})^{0.21\pm0.08}$. Further, surface density of the clouds (Σ_{cl}) influences the $\Delta V - L_{cl}$ relation, with $\Delta V \propto (L_{cl} \times \Sigma_{cl})^{0.50\pm0.13}$. This indicates that gravitational energy drives turbulence in clouds, indicating possible virial equilibrium. We observe that L_{cl} correlates with M_{cl} and volume gas density of the cloud (ρ_{cl}), implying nearly constant Σ_{cl} across the clouds. In cloud cores, $C^{18}O$ linewidth data shows complex behaviour, with no direct correlation between ΔV and core size (L_{co}). However, a positive correlation emerges when the surface density of the core is included in L_{co}. Notably, the volume gas density (ρ_{co}) and core size (L_{co}) relation deviates from constant core surface density. Our analysis reveals that turbulent pressure increases with gravitational pressure to maintain global equilibrium. Finally, on the core-to-cloud scale, physical relationships remain continuous, reflecting the interconnected nature of clouds and cores. Extending our previous work, where we demonstrated a non-linear dependence of turbulence on the alignment of the local magnetic field in molecular clouds with the Galactic Plane. We compare observations with a theoretical model based on kinetic theory. Our result confirms that higher turbulence causes greater magnetic misalignment

consistent with the derived second-order polynomial relationship. This work has been done in collaboration with B. Barman,and P. Byakti.

Unveiling the properties of asteroids: linking photopolarimetry to spectral classification

This paper attempts to present a comprehensive analysis of the photopolarimetric properties of asteroids. In light of the limitations identified in several previously employed empirical formulae, this paper introduces a new formula that offers a reliable fit for the phase-polarization curve of asteroids. The validity of the new empirical formula is confirmed by analyzing polarimetric data for lunar soil samples across a wide range of phase angles and various spectral bands. Notably, this investigation reveals a strong negative correlation between P_{max} and wavelength (λ) for lunar soil samples. Furthermore, the examination of key features of the phase-polarization curve of asteroids, such as the polarization minimum (P_{min}), polarization maximum (P_{max}), and the slope (h) at the inversion angle, allows us to explore their correlations with the geometric albedo (A) of asteroids. We have investigated whether our photopolarimetric studies could corroborate the existing classification scheme for asteroids, which divides them into three major composition classes: Chondrite (C), Metallic (M), and Stony (S)-types, based on spectral analysis. Interestingly, our findings have revealed a good agreement with the existing classification. Each class is characterized by a specific combination of geometric albedo (A) and polarimetric properties (P_{min}, P_{max} and h) observed in asteroids, represented by four distinct regions. Interestingly, besides the three main types (C-, M-, and S-), we have found an overlapping region containing both M- and S-type asteroids. This work has been done in collaboration with B. Prasad.

Prasanta Kumar Das

Constructing Viable Interacting Dark Matter and Dark Energy Models: A Dynamical Systems Approach

We study the evolution of k=-1 FLRW cosmological models for two interacting Dark Matter-Dark Energy Models using dynamical system analysis. Since we are interested in late time evolution, the sign of the interaction term is chosen such that it facilitates the transfer of energy from dark matter to dark energy. We also explore the k=0 invariant subspace of these models. We find that both these models have sectors which have a stable fixed point where we can recover an accelerating universe with a negative equation of state. This indicates these can be viable models for our universe. We also rule out certain sectors of these models because they do not give the correct late time observational features. We observe that although we start with a dust-like Dark Matter, its effective equation of state evolves due to its interaction with Dark Energy. As a result, the Dark Matter can display features of stiff matter and exotic matter in the course of evolution. This work has been done in collaboration with Ashmita,and Kinjal Banerjee.

Freeze-In Dark Matter Search at Colliders with Jet Substructure Analysis

The non-thermally produced freeze-in dark matter is an attractive alternative to look beyond the weakly interacting massive particle (WIMP) paradigm. With the singlet-doublet dark matter model, a simple extension to the Standard Model (SM), we probe the light dark matter parameter space, assuming feeble couplings between SM particles and the dark matter candidate. We tried to show that in the non-standard cosmological background, a collider probe using jet substructure analysis can be very effective in terms of exclusion capability and serve as a complimentary probe to the existing displaced vertex searches. This work has been done in collaboration with Saumyen Kundu, Sudipta Show, and Partha Konar.

Shyam Das

Complexity Characterization in modeling Anisotropic Compact Stellar Structures

In this study, we present an exact solution to the Einstein field equations, featuring a static, spherically symmetric, anisotropic compact stellar fluid sphere with non-zero complexity. The model is constructed using a specific metric potential for the g_{tt} component, along with a defined complexity profile. The model parameters are fixed by ensuring the continuity of the interior and exterior metrics across the surface of the star and by setting the radial pressure to zero across the boundary. The stability of the model has been analyzed by verification of different standard conditions. Validation of our model is supported by recent observational data from well-known pulsars. This work has been done in collaboration with Megandhren, and Somi Aktar.

Study of compact objects: A new analytical stellar model

In this paper, we obtain analytical solutions of Einstein field equations for a spherically symmetric anisotropic matter distributions. For this purpose physically meaningful metric potential corresponds to grr and a particular choice of the anisotropy has been utilized to obtain the solutions in closed form. This class of solution has been used to characterized observed pulsars from different aspects. Smooth matching of interior spacetime metric with the exterior Schwarzschild metric and in addition with the condition of vanishing radial pressure across the boundary leads us to determine the model parameters. Pulsar $4U1820^{\wedge\prime}30$ with its current estimated data for mass and radius (Mass = 1.587 $M_{\odot}$ and radius = 9.1 km) has been allowed for testing the physical acceptability of our developed model. We have graphically analyzed the gross physical features of the observed pulsar. The stability of the model is also discussed under the conditions of causality, adiabatic index and generalized Tolman–Oppenheimer–Volkov(TOV) equation under the forces acting on the system. Few more pulsars with their have been considered, to show that this model is compatible with observational data, and all the requirements of a realistic star are highlighted. Mass-radius ($M_{\imath}R$) relationship have been generated for our model. The impact of anisotropy on the gross physical features of stars have been explored with the graphical presentation. This work has been done in collaboration with Koushik Chakraborty, Farook Rahaman, Shreya Majumde.

Sudipta Das

Study of pressure parametric dark energy model in the framework of $f(Q)$ gravity

In this work, we have proposed a simple parametrization for the pressure component $p(z)$ of the dark energy model and have studied the cosmological implications of this model in the framework of $f(Q)$ modified gravity theory, aka, the symmetric teleparallel gravity theory, where Q is known as the nonmetricity scalar. By considering a particular parametric form of $p(z)$, we obtained the Hubble solution for the $f(Q)$ modified gravity model. In order to see whether this model is consistent with or challenges the ΛCDM limits, we tried to put constraints on the model parameters using the recent observational datasets like Hubble data, Cosmic Chronometer data, Type Ia Supernovae (SNIa) data, baryonic acoustic oscillations (BAO) data. We have employed the χ^2 minimization technique and have carried out the Markov Chain Monte Carlo (MCMC) analysis using emcee package. We have found that the deceleration parameter shows a smooth transition from positive to negative value in recent past which is essential for the structure formation of the Universe. It has been found that the parametric form of the dark energy pressure parameter is consistent with current cosmological scenario. This work has been done in collaboration with Sangita Goswami.

Ujjal Debnath

Spherically Symmetric Anisotropic Charged Neutron Stars in $f(Q,T)$ Gravity

In this work, we have investigated a new solution for charged anisotropic compact stellar system in the framework of an extended theory of symmetric teleparallel gravity known as $f(Q,T)$ gravity with the non-metricity term Q and the trace T for energy-momentum tensor. We have constructed a complete set of the gravitational field equations for a non-linear function $f(Q,T) = \alpha Q + \beta(1+Q^2) + \lambda T$ with α, β and λ are dimensionless constant parameters in case of static spherically symmetric space-time. To evaluate the expression of relevant unknown constants interior space-time has been matched with exterior Reissner-Nordström metric. We have performed a graphical discussion in detail to test the behavior of physical parameters in the interior region of a stellar system like energy density, radial and tangential pressure, anisotropies of matter portion, electric field intensity etc. Also, to check the physical validity of our solutions, we have performed various tests viz., energy conditions, stability, mass-radius relation, surface redshift etc. The hydrostatic equilibrium position of our stellar system has been analysed through the TOV equation. Finally, we have determined that our stellar structure solutions satisfy all required physical conditions for viability and acceptability in the context of some pulsar like neutron stars. So our model can be used to characterise the neutron stars in $f(Q,T)$ modified gravity.This work has been done in collaboration with Krishna Pada Das.

New Black Hole Solutions in $f(P)$ Gravity and their Thermodynamic Properties

Black holes are the fascinating objects in the universe. They represent extreme deformations in spacetime geometry. Here, we construct $f(P)$ gravity and

the first example of static-spherically symmetric black hole solution in $f(P)$ gravity and discuss their thermodynamics. Using the numerical approach and series solution, we discover the solution and demonstrate that it is a generalization of Schwarzschild. The solution is characterized by a single function that satisfies a non-linear fourth-order differential equation. Interestingly, we can analytically calculate the solution's specific heat, Wald entropy, and Hawking temperature as a function of horizon radius. After analyzing the specific heat, we discovered that the black hole is thermodynamically stable over a small horizon radius. This work has been done in collaboration with Aniruddha Ghosh.

Shantanu Desai

A stacked search for spatial coincidences between IceCube neutrinos and radio pulsars

We carry out a stacked search for spatial coincidences between all the known radio pulsars and TeV neutrinos from the IceCube 10 year (2008-2018) muon track data, as a followup to our previous work on searching for spatial coincidences with individual pulsars. We consider three different weighting schemes to stack the contributions from each pulsar. We do not find a statistically significant excess using this method. We report the 95% c.l. neutrino flux upper limit as a function of the neutrino energy. We have also made our analysis codes publicly available. This work has been done in collaboration with Vibhavasu Pasumarti.

Search for Dark Matter Annihilation to gamma-rays from SPT-SZ selected Galaxy Clusters

We search for dark matter annihilation from galaxy clusters in the energy range from 1-300 GeV using nearly 16 years of Fermi-LAT data. For this purpose, we use 350 galaxy clusters selected from the 2500 deg^2 SPT-SZ survey. We model the dark matter distribution using the NFW profile for the main halo along with the Einasto profile for the substructure. The largest signal is seen for the cluster SPT-CL J2021-5257 with a significance of around 3σ. The best-fit dark matter mass and annihilation cross-section for this cluster are equal to (60.0 ± 11.8) GeV and $\langle \sigma v \rangle = (6.0 \pm 0.6) \times 10^{-25} \mathrm{cm}^3\mathrm{s}^{-1}$ for the $\bar{b}b$ annihilation channel. However, this central estimate is in conflict with the limits on annihilation cross-section from dwarf spheroidal galaxies, and hence cannot be attributed to dark matter annihilation. Three other clusters show significance between $2 - 2.5\sigma$, whereas all the remaining clusters show null results. The most stringent 95% c.l. upper limit for the WIMP annihilation cross-section among all the clusters is from SPT-CL J0455-4159, viz. $\langle \sigma v \rangle = 6.44 \times 10^{-26} \mathrm{cm}^3\mathrm{s}^{-1}$ for $m_\chi = 10$ GeV and $b\bar{b}$ annihilation channel. This work has been done in collaboration with Siddhant Manna.

Moon Moon Devi

Impact of scalar NSI on the neutrino mass ordering sensitivity at DUNE, HK and KNO

The study of neutrino non-standard interactions (NSI) is a well-motivated phenomenological scenario to explore new physics beyond the Standard Model. The possible scalar coupling of neutrinos (ν) with matter is one of such new physics scenarios that appears as a sub-dominant effect that can impact the ν-oscillations in matter. The presence of scalar NSI introduces an additional contribution directly to the ν-mass matrix in the interaction Hamiltonian and subsequently to the ν-oscillations. This indicates that scalar NSI may have a significant impact on measurements related to ν-oscillations e.g. leptonic CP phase (δ_{CP}), θ_{23} octant and neutrino mass ordering (MO). The linear scaling of the effects of scalar NSI with matter density also motivates its exploration in long-baseline (LBL) experiments. In this paper, we study the impact of a scalar-mediated NSI on the MO sensitivity of DUNE, HK and HK+KNO, which are upcoming LBL experiments. We study the impact on MO sensitivities at these experiments assuming that scalar NSI parameters are present in nature and is known from other non-LBL experiments. We observe that the presence of diagonal scalar NSI elements can significantly affect the ν-mass ordering sensitivities. We then also combine the data from DUNE with HK and HK+KNO to explore possible synergy among these experiments in a wider parameter space. We also observe a significant enhancement in the MO sensitivities for the combined analysis. This work has been done in collaboration with Arnab Sarker, Abinash Medhi, and Dharitree Bezboruah.

Neutrino Oscillations in Presence of Diagonal Elements of Scalar NSI: An Analytic Approach

Scalar Non-Standard Interactions (SNSI) in neutrinos can arise when a scalar mediator couples to both neutrinos and standard model fermions. This beyond the Standard Model (BSM) scenario is particularly interesting as the SNSI contribution appears as

a density-dependent perturbation to the neutrino mass, rather than appearing as a matter-induced potential, and the neutrino oscillation probabilities uniquely depend on the absolute neutrino masses. In this work, we show the complex dependence of the SNSI contributions on the neutrino masses and discuss how the mass of the lightest neutrino would regulate any possible SNSI contribution in both mass ordering scenarios. We derive the analytic expressions for neutrino oscillation probabilities, employing the Cayley-Hamilton theorem, in the presence of diagonal elements of SNSI. The expressions are compact and show explicit dependence on matter effects and the absolute neutrino masses. The analytic expressions calculated here allow us to obtain the dependence of the SNSI contribution on mass terms of the form $m_1 + m_2$, $m_2 - m_1$, $m_1 c_{12}^2 + m_2 s_{12}^2$, $m_1 s_{12}^2 + m_2 c_{12}^2$, and m_3. We then explore the non-trivial impact of neutrino mass ordering on the SNSI contribution. The dependence of the SNSI contribution on the 3ν parameters is thoroughly explored using our analytic expressions. This work has been done in collaboration with Dharitree Bezboruaha, Dibya S. Chattopadhyayb,Abinash Medhic, and Arnab Sarkera.

Praveen Kumar Dhankar

Holographic principle inspired dark energy description of unified early and late universe in viscous mimetic gravity

In this study, we explore the mimetic matter model proposed by Chamseddine and Mukhanov (2013), utilizing the holographic principle to coherently describe both the early and late universe when bulk viscosity is present in the inhomogeneous equation of state. Our examination of the universe's evolution is based on the generalized infrared-cutoff holographic dark energy model detailed by Nojiri and Odintsov (2017) within the context of the flat FRW model. From a holographic perspective, we derive the energy conservation equation incorporating mimetic matter through a viscous holographic fluid model. Furthermore, we analyze various scenarios of bulk viscosity by assuming a constant equation of state parameter and derive the infrared cut-off expression in terms of the particle horizon. We demonstrate that within the framework of mimetic gravity, there is a class of solutions comparable to those in General Relativity, with an additional contribution from a non-relativistic mimetic matter component. These solutions can effectively describe dark matter. This work has been done in collaboration with G.S. Khadekar, Saibal Ray, and Aritra Sanyal.

Perturbations with bulk viscosity in modi

In this work, we investigate cosmological perturbations of viscous modified chaplygin gas model. Using 1 + 3 covariant formalism, we define covariant and gauge invariant gradient variables, which after the application of scalar decomposition and harmonic decomposition techniques together with redshift transformation method, provide the energy overdensity perturbation equations in redshift space, responsible for large-scale structure formation. In order to analyze the effect of the viscous modified chaplygin gas model on matter overdensity contrast, we numerically solve the perturbation equations in both long and short wavelength limits. The numerical results show that the energy overdensity contrast decays with redshift. However, the perturbations which include amplitude effects due to the viscous modified chaplygin model do differ remarkably from those in the $\wedge$ CDM. In the absence of viscous modified chaplygin model, the results reduce to those of $\wedge$ CDM. This work has been done in collaboration with Albert Munyeshyaka, and Joseph Ntahompagaze

Archana Dixit

Properties of interacting quark star in light of Rastall gravity

Interacting quark matter equation of state within the framework of Rastall gravity, a modified theory of gravity. We derive the mass-radius relationships and calculate the maximum gravitational masses and their corresponding radii, comparing these results under both Rastall gravity and general relativity. Our analysis incorporates recent observational data, including the GW190425 event, to constrain the model parameters (λ, η, B_{eff}). We also assess the stability of these QSs by evaluating their static stability, adiabatic index, and sound velocity profiles, thus confirming their viability within the modified gravitational framework. This work has been done in collaboration with Ayan Banerjee1, Anirudh Pradhan, and Izzet Sakall.

Observational constraint in $f(R, \nabla R)$ gravity model in power-law cosmology

In this paper, we have considered the flat Friedmann-LemaÃ®tre-Robertson-Walker (FRW) model in the framework of $f(R, \nabla R)$ gravity. We

have analyzed the significance of bulk viscosity in the $f(R, \nabla R)$gravity model to study the expansion of the universe.We have considered two bulk viscosity parameterizations and the use of power-law cosmology to constrain themodel parameters H0 and q. Using the Bayesian analysis and likelihood function in conjunction with the Markov Chain Monte Carlo method, we obtained the model parameters $H0 = 70.76732 + 0.00010 - 0.00088 and q = -0.6478 + 0.000091 - 0.000075$. The behaviors of energy density, bulk viscous pressure, and the effective equation of the state parameter with redshift are investigated in detail. These features demonstrate that the bulk viscosity is a valid candidate for acquiring the negative pressure needed to effectively drive the expansion of the universe. To check the validity of the $f(R, \nabla R)$ model, we also analyze the behavior of energy conditions. The adiabatic squared speed of the sound is used to test the model's stability. The Om(z) diagnostic is used in the model to identify the quintessence and phantom regions.

Jibitesh Dutta

Modelling the Accelerating Universe with $f(Q)$ Gravity: Observational Consistency

In this paper, we present a cosmological model within the framework of symmetric teleparallel gravity, focusing on $f(Q)$ gravity, where Q represents the non-metricity scalar. Utilizing cosmological datasets, we derive an accelerating cosmological model by constraining its free parameters. To achieve this, we determine the parametric form of the Hubble parameter using a well-motivated $f(Q)$ function. Remarkably, all obtained values fall within the range suggested by cosmological observations. By employing the best-fit parameters, we calculate the present geometrical parameters and demonstrate the accelerating behaviour of the Universe. Furthermore, we thoroughly examine the evolutionary behaviours of the Universe, noting that our model converges to the ΛCDM model at late times. Finally, we investigate the energy conditions and find a violation of the strong energy condition, which could provide a valuable understanding of the nature of dark energy. This work has been done in collaboration with S.A. Narawade, S.H. Shekh, B. Mishra,and W. Khyllep.

Gurudatt Gaur

Investigating the kinetic effects on current gradient-driven instabilities of electron current layers via particle-in-cell simulations

Electron current layers, which form in various natural and laboratory plasmas, are susceptible to multiple instabilities, with tearing being a prominent instability driven by current gradients. Tearing is considered a potential mechanism for magnetic reconnection in collisionless regimes, where electron inertia acts as a non-ideal factor that causes magnetic field lines to break and reconnect. In contrast, another mode, known as the surface-preserving mode, also driven by current gradients, maintains the magnetic field topology. In this study, we investigate the kinetic effects on these modes in the presence of finite electron temperatures using two-dimensional particle-in-cell simulations. Our findings reveal that temperature significantly stabilizes the tearing mode, particularly at higher temperatures, due to an increased electron Larmor radius and the associated magnetic field diffusion. We also examine the interplay between the guide field and temperature. Additionally, we observe that growth rates for the surface-preserving mode, in contrast to the tearing mode, increase with temperature, likely due to enhanced electron flow velocities. Furthermore, we identify cases with mixed modes, where both tearing and surface-preserving modes coexist, exhibiting asymmetric structures characteristic of asymmetric magnetic reconnection. Finally, we outline potential future research directions that build upon our findings. This work has been done in collaboration with Sushmita Mishra, and Bhavesh G Patel

Detection of gravitational wave signals from precessing binary black hole systems using convolutional neural networks

Current searches for gravitational waves (GWs) from black hole binaries using the LIGO and Virgo observatories are limited to analytical models for systems with black hole spins aligned (or antialigned) with the orbital angular momentum of the binary. Detecting black hole binaries with precessing spins (spins not aligned or antialigned with the orbital angular momentum) is crucial for gaining unique astrophysical insights into the formation of these sources. Therefore, it is essential to develop a search strategy capable of identifying compact binaries with precessing spins. Aligned-spin waveform models are

inadequate for detecting compact binaries with high precessing spins. While several efforts have been made to construct template banks for detecting precessing binaries using matched filtering, this approach requires many templates to cover the entire search parameter space, significantly increasing the computational cost. This work explores the detection of GW signals from binary black holes (BBH) with both aligned and precessing spins using a convolutional neural network (CNN). We frame the detection of GW signals from aligned or precessing BBH systems as a hierarchical binary classification problem. The first CNN model classifies strain data as either pure noise or noisy signals (GWs from BBH). A second CNN model then classifies the detected noisy signal data as originating from either precessing or nonprecessing (aligned/antialigned) systems. Using simulated data, the trained classifier distinguishes between noise and noisy GW signals with more than 99% accuracy. The second classifier further differentiates between aligned and highly precessing signals with around 95% accuracy. We extended our analysis to a multidetector framework by performing a coincident test. Additionally, we tested the performance of our trained architecture on data from the first three observation runs (O1, O2, and O3) of LIGO and Virgo to identify detected BBH events as either aligned or precessing. This work has been done in collaboration with Chetan Verma, Amit Reza, Dilip Krishnaswamy, and Sarah Caudill

Sakshi Gautam

Re-visiting the role of short-range correlations on neutron-star properties

The impact of short-range correlations (SRCs) on neutron star (NS) properties are re-examined across various classes of relativistic mean-field (RMF) models. The coupling strengths of the models are so adjusted that the low-density part of the equation of state (EoS), complemented with saturation properties such as binding energy of symmetric nuclear matter and nuclear symmetry energy responsible for the bulk properties of finite nuclei, remains practically unaffected with the inclusion of SRCs. The EoS for symmetric nuclear matter and the nuclear symmetry energy at supra-saturation densities which governs the EoS for NS matter become softer or stiffer in the presence of the SRCs, depending on the type of RMF model considered. These distinct effects of SRCs are observed to be more significant at higher densities, as expected, when behaviour of the EoS at low densities, which govern the finite nuclei physics, is not compromised. For most of the models with self-couplings of scalar and vector mesons, the EoS of symmetric nuclear matter stiffens, with a slight effect on nuclear symmetry energy with the inclusion of SRCs. Conversely, in the models incorporating cross-couplings between mesons, the addition of SRCs leads to softer symmetry energy, compensating the stiffening effect of the EoS of symmetric nuclear matter. With the inclusion of SRCs, the values of radius and tidal deformability of canonical mass star and maximum mass of NSs for realistic EoSs align well the present constraints on astrophysical observations. This work has been done in collaboration with Anagh Venneti, Sarmistha Banik, and B. K. Agrawal.

Unraveling the global behavior of equation of state by explicit finite nuclei constraints

We obtain posterior distribution of equations of state (EOSs) across a broad range of density by imposing explicitly the constraints from precisely measured fundamental properties of finite nuclei, in combination with experimental data from heavy-ion collisions and astrophysical observations of radius, tidal deformability and minimum-maximum mass of neutron stars. The acquired EOSs exhibit a distinct behavior compared to those usually obtained by imposing the finite nuclei constraints implicitly through empirical values of selected key parameters describing symmetric nuclear matter and symmetry energy in the vicinity of saturation densities. The explicit treatment of finite nuclei constraints yields softer EOSs at low densities which eventually become stiffer to meet the maximum mass criteria. The radius measurements derived from NICER and HESS J1731-347 exhibit favorable agreement with the posterior distribution of radius determined through our explicitly constrained EOSs. The Kullback-Leibler divergence has been used to perform a quantitative comparison of the distributions of the EOSs resulting from implicit and explicit finite nuclei constraints. This work has been done in collaboration with Anagh Venneti, Sakshi Gautam1, and B. K. Agrawal.

Prabir Gharami

Theoretical Studies on Mass Transfer in Binary Stars: Retrospect and Prospects

This review article comprehensively examines the advancements, methodologies, and critical findings about the mass transfer process in binary stars, offering an in-depth analysis of its fundamental principles and recent developments. The study systematically evaluates contemporary research, highlighting significant theoretical and experimental contributions that have shaped the area. Furthermore, the article critically synthesizes existing literature to identify key challenges, research gaps, and potential directions for future investigation. The review also explores the interdisciplinary relevance of the process of mass transfer, discussing its integration with cutting-edge technologies and innovative frameworks. By providing a detailed comparative analysis of various approaches, this work aims to offer a structured understanding of the state-of-the-art advancements while proposing strategic research directions to address unresolved issues. The insights presented in this article are expected to facilitate the development of more robust, efficient, and scalable solutions in theoretical astrophysics. This synthesis serves as a valuable resource for researchers, fostering further exploration and innovation in the field.

Abhik Ghosh

Wideband intensity mappingTowards 21*-cm intensity mapping at* $z = 2.28$ *with uGMRT using the tapered gridded estimator – IV. Wideband analysis*

We present a Wideband Tapered Gridded Estimator (TGE), which incorporates baseline migration and variation of the primary beam pattern for neutral hydrogen (Hi) 21-cm intensity mapping (IM) with large frequency bandwidth radio-interferometric observations. Here we have analysed $394 - 494\,\mathrm{MHz}$ ($z = 1.9 - 2.6$) uGMRT data to estimate the Multi-frequency Angular Power Spectrum (MAPS) $C_\ell(\Delta\nu)$ from which we have removed the foregrounds using the polynomial fitting (PF) and Gaussian Process Regression (GPR) methods developed in our earlier work. Using the residual $C_\ell(\Delta\nu)$ to estimate the mean squared 21-cm brightness temperature fluctuation $\Delta^2(k)$, we find that this is consistent with $0 \pm 2\sigma$ in several k bins. The resulting 2σ upper limit $\Delta^2(k) < (4.68)^2\,\mathrm{mK}^2$ at $k = 0.219\,\mathrm{Mpc}^{-1}$ is nearly 15 times tighter than earlier limits obtained from a smaller bandwidth (24.4 MHz) of the same data. The 2σ upper limit $[\Omega_{Hi} b_{Hi}] < 1.01 \times 10^{-2}$ is within an order of magnitude of the value expected from independent estimates of the Hi mass density Ω_{Hi} and the Hi bias b_{Hi}. The techniques used here can be applied to other telescopes and frequencies, including $\sim 150\,\mathrm{MHz}$ Epoch of Reionization observations. This work has been done in collaboration with Khandakar Md Asif Elahi, Somnath Bharadwaj, Srijita Pal, Sk. Saiyad Ali, and Samir Choudhuri et. al.

Shubhrangshu Ghosh

Spherical accretion in the Schwarzschild spacetime in the Newtonian analogous construct

The velocity-dependent Newtonian analogous potentials (NAPs) corresponding to general relativistic (GR) spacetimes accurately capture most of the relativistic features, including all classical tests of GR, effectively representing spacetime geometries in Newtonian terms. The NAP formulated by Tejeda & Rosswog (TR13) for Schwarzschild spacetime has been applied to the standard thin accretion disk around a black hole (BH) as well as in the context of streamlines of noninteracting particles accreting onto a Schwarzschild BH, showing good agreement with the exact relativistic solutions. As a further application, here we explore the extent to which TR13 NAP could describe a transonic hydrodynamical spherical accretion flow in Schwarzschild spacetime within the framework of standard Newtonian hydrodynamics. Instead of obtaining a typical single "saddle-type" sonic transition, a "saddle-spiral pair" is produced, with the inner sonic point being an (unphysical) "spiral type" and the outer being a usual "saddle type." The Bondi accretion rate at outer sonic radii, however, remains consistent with that of the GR case. The primary reason for the deviation of our findings from the classical Bondi solution is likely due to the inconsistency between the Euler-type equation in the presence of velocity-dependent TR13 NAP within the standard Newtonian hydrodynamics framework, and the corresponding GR Euler equation, regardless of the fluid's energy. Our study suggests that a (modified) hydrodynamical formalism is needed to effectively implement such potentials in transonic accretion studies that align with the spirit of TR13-like NAP, while remaining consistent with the GR hydrodynamics. This could then essentially circumvent GR hydrodynamics

or GR magnetohydrodynamics equations. This work has been done in collaboration with Souvik Ghose, Kalyanbrata Pal, Arunabha Bhadra, Tapas K. Das.

Sushant G. Ghosh

Strong Gravitational Lensing by Rotating Quantum-Corrected Black Holes: Insights and Constraints from EHT Observations of M87 and Sgr A**

We study gravitational lensing in the strong-field limit using the rotating quantum-corrected black hole (RQCBH) with an additional parameter α besides mass M and spin parameter a. We discover a decrease in the deflection angle α_D, the photon sphere radius x_{ps}, and the angular position θ_∞. The flux ratio of the first image to all subsequent images, r_{mag}, decreases rapidly as α increases. We compare RQCBH observables with those of Kerr black holes, using Sgr A* and M87* as lenses to observe the effect of the quantum-corrected parameter α. For Sgr A*, the angular position θ_∞ in $\in$ $(14.8 - 26.3)$ μas, while for M87* $\in$ $(11.12 - 19.78)$ μas. The angular separation s, for supermassive black holes (SMBHs) SgrA* and M87*, differs significantly, with values ranging $\in$ $(0.033 - 0.79)$ μas for Sgr A* and $\in$ $(0.033 - 0.59)$ μas for M87*. The deviations of the lensing observables $|\Delta\theta_\infty|$ and $|\Delta s|$ for RQCBH $(a = 0.8, \alpha = 0.4)$ from Kerr black holes can reach up to 1.6 μas and 0.41 μas for Sgr A*, and 1.2 μas and 0.31 μas for M87*. The relative magnitude r_{mag} $\in$ $(1.81 - 6.82)$ μas. We also compared the time delays between the relativistic images in the 22 SMBHs at the center of various galaxies. We found that RQCBH can be quantitatively distinguished from Kerr black holes. Interestingly, the time delay for Sgr A* and M87* can reach approximately 6.0127 min and 308.15 hrs, respectively. Our analysis concludes that, within the 1σ region, a significant portion of the parameter space agrees with the EHT results of M87* and Sgr A*. This work has been done in collaboration with Amnish Vachher

Investigating Rotating Black Holes in Bumblebee Gravity: Insights from EHT Observations

The EHT observation revealed event horizon-scale images of the supermassive black holes Sgr A* and M87* and these results are consistent with the shadow of a Kerr black hole as predicted by general relativity. However, Kerr-like rotating black holes in modified gravity theories can not ruled out, as they provide a crucial testing ground for these theories through EHT observations. It motivates us to investigate the Bumblebee theory, a vector-tensor extension of the Einstein-Maxwell theory that permits spontaneous symmetry breaking, resulting in the field acquiring a vacuum expectation value and introducing Lorentz violation. We present rotating black holes within this bumblebee gravity model, which includes an additional parameter ℓ alongside the mass M and spin parameter a - namely RBHBG. Unlike the Kerr black hole, an extremal RBHBG, for $\ell < 0$, refers to a black hole with angular momentum $a > M$. We derive an analytical formula necessary for the shadow of our rotating black holes, then visualize them with varying parameters a and ℓ, and also estimate the black hole parameters using shadow observables viz. shadow radius R_s, distortion δ_s, shadow area A and oblateness D using two well-known techniques. We find that ℓ incrementally increases the shadow size and causes more significant deformation while decreasing the event horizon area. Remarkably, an increase in ℓ enlarges the shadow radius irrespective of spin or inclination angle θ_0. This work has been done in collaboration with Shafqat Ul Islam,and Sunil D. Maharaj.

Ankur Gogoi

Cellulose acetate-based gel electrolytes grafted with surface-functionalized SiO_2 nanofiber for green energy storing applications

The utilisation of gel electrolytes based on cellulose acetate (CA) has garnered considerable interest in the field of energy storage devices owing to its intrinsic flexibility, safety, and environmentally friendly characteristics. The primary aim of this study is to investigate the improved properties of cellulose acetate (CA)-based gel electrolytes by grafting SiO_2 nanofibers onto the CA matrix, as opposed to the conventional method of dispersing SiO_2 nanofibers inside the gel. We used CA's biodegradability and SiO_2 nanofibers' distinctive structure to improve the gel electrolyte's ionic conductivity and performance. The CA matrix was integrated with Octadecyltrichlorosilane (OTS) functionalized SiO_2 nanofibers (g-SiO_2) by a systematic synthesis procedure, creating a nanocomposites gel polymer electrolyte (NGPE) material with enhanced electrical, electrochemical, and thermal properties. An increase in ionic conductivity was seen as the concentration of grafting increased, up to a maximum room-temperature ionic conductivity of 3×10^{-3}

S/cm at 7.5 wt%. The grafted NGPEs also showed an outstanding cationic transport number (0.73), an excellent electrochemical potential window (4.8 V) and enhanced interfacial compatibility with metal electrodes as compared with the electrolyte samples without nanofibers. Thermal properties are also enhanced in grafted nanocomposite electrolytes. Theoretical calculations based on density functional theory (DFT) substantiated the establishment of a stable CA+SiO_2+OTS compound in its ground state optimisation and potential pathways for Li^+ migration within the NGPEs. This work has been done in collaboration with Masum Das, Nishant Shukla, Bitupon Boruah, Lakshi Saikia et al.

Simultaneous Removal of As(III) and As(V) from Aqueous Solution by Using Iron-Functionalized Polythiophene: A Novel Approach toward Water Treatment

Arsenic contamination in groundwater poses a significant threat to human health, affecting millions worldwide. This study presents a novel approach for simultaneous remediation of both As(III) and As(V) by using iron-functionalized polythiophene (PTh@Fe) composites. The PTh@Fe composite was synthesized by a reduction process involving $FeCl_2/FeCl_3$ byproducts of polymerization, resulting in a highly efficient adsorbent for both As(III) and As(V) species. The investigation systematically examined key parameters influencing arsenic removal, including adsorbent dosage, pH, initial arsenic concentration, and contact time. The composite exhibited exceptional adsorption capacities, with maximum removal percentages of 98.7% for As(III) and 98.8% for As(V) under the optimized conditions. Thermodynamic and kinetic analyses suggested endothermic and spontaneous adsorption processes following a pseudo 2nd-order mechanism. Furthermore, the Langmuir isotherm model provided an excellent fit to the experimental data, with maximum adsorption capacities of 8.62 mg/g for As(V) and 7.57 mg/g for As(III). Density functional theory (DFT) calculations confirmed the feasibility of arsenic adsorption onto iron species in various oxidation states, offering valuable theoretical insights into the process. Furthermore, the composite demonstrated good reusability over multiple adsorption-desorption cycles and tolerance to coexisting anions, highlighting its practical applicability for water purification. This research demonstrates the potential of iron-functionalized polythiophene composites as a promising solution for addressing arsenic contamination in water sources, bridging the gap between innovative materials and theoretical understanding in environmental science and water treatment technologies. This work has been done in collaboration with Rupkamal Chetia, Shrutipriya Devi, Nishant Shukla, Abhishek Hazarika, et al.

Umananda D. Goswami

Main sequence of star formation and colour bimodality considering galaxy environment

This study involves the use of friend-of-friend method on the volume limited samples constructed from the Sloan Digital Sky Survey Data Release 12 (SDSS DR12) to classify the galaxies into isolated and non-isolated environments hence to investigate the influence of the galaxy environment on the main sequence of star formation, and colour bimodality. We classified the galaxies into the luminous volume-limited sample with $-22.5 \leq M_r \leq -20.5$ (mag), and the faint volume-limited sample with $-20.5 \leq M_r \leq -18.5$ (mag). Using the WHAN diagnostic diagram we assignedthe samples into star-forming, strong AGN, weak AGN, and retired galaxies based on their environment (isolated and non-isolated). The friend-of-friend method was successful in producing consistent results regarding the stellar mass-SFR and stellar mass-colour known relations. Apart from that the decrease in the slope of the main sequence for star-forming galaxies by 0.04 dex and intercept by 0.39 dex for the luminous sample was observed while the faint sample a decrease of 0.08 dex in slope and 0.74 dex in intercept was observed between isolated and non-isolated galaxies. A significant difference on the number of galaxies between isolated and non-isolated galaxies within, above and below the main sequence by 7.47%, 28.51%, 14.59% for the luminous sample while for the faint sample by 16.15%, 32.60%, 35.23% on average, respectively are observed. A significant difference in the number of galaxies in the blue cloud, green valley, and red sequence by 10.30%, 20.61%, 5.74% for luminous sample while for faint sample by 28.46%,41.36%, 8.95% on average, respectively was observed. The study concludes that the galaxy environment influences the shaping and positioning of galaxies along the star formation main sequence and colour bimodality. This study has been done in collaboration with Pius Privatus.

Propagation and Fluxes of Ultra-High Energy Cosmic Rays in $f(R)$ Gravity Theory

In this work, we study the effect of diffusion of ultra-high energy cosmic ray (UHECR) protons in the presence of turbulent magnetic fields (TMFs) in the light of the $f(R)$ theory of gravity. The $f(R)$ theory of gravity is a successful modified theory of gravity in explaining the various aspects of the observable Universe including its current state of expansion. For this work, we consider two most studied $f(R)$ gravity models, viz., the power-law model and the Starobinsky model. With these two models, we study the diffusive character of the propagation of UHECR protons in terms of their density enhancement. The density enhancement is a measure of how the density of CRs changes due to their diffusion in the intergalactic medium and interaction with the cosmic microwave background (CMB) radiation. Ankle, instep and Greisen–Zatsepin–Kuzmin (GZK) cutoff are all spectrum characteristics that extragalactic UHECRs acquire when they propagate through the CMB. We analyse all these characteristics through the diffusive flux as well as its modification factor. Model dependence of the modification factor is minimal compared to the diffusive flux. We compare the UHECR proton spectra calculated for the considered $f(R)$ gravity models with the available data of the Telescope Array (TA) and Pierre Auger Observatory (PAO). We see that both models of $f(R)$ gravity predict energy spectra of UHECRs with all experimentally observed features, which lay well within the range of combined data of both experiments throughout the energy range of concern. It is to be noted that our present work is only to investigate the possible effects of $f(R)$ gravity theory on the UHECRs propagation, using pure proton composition as a simplified case study since protons are least affected by magnetic fields. Hence, at this stage, our results cannot be used to favor or disfavor $f(R)$ cosmology over CDM cosmology as more work is needed in this regard. This work has been done in collaboration with Swaraj Pratim Sarmah.

Shivappa B. Gudennavar

Constraining the physical parameters of XTE J1701-462 through NuSTAR observations

The spectral properties of the transient neutron star low-mass X-ray binary XTE J1701-462 were studied using the data obtained from FPMA/B detectors onboard NuSTAR during its second known outburst (2022 September). The physical parameters of the system were derived from the analysis of the data in the 3.0-30.0 keV energy range. The patterns displayed on the hardness-intensity diagram of the three observations closely resembled the banana branch/normal branch, a vertex of horizontal and normal branch of the Z-track and a transition from normal branch to flaring branch. Spectral analysis of the source revealed the presence of Fe K emission complex. The source spectra were fitted with a multitemperature blackbody (diskbb) component in conjunction with the reflection model (relxillNS). The values of temperature (kT_{in}) and radius (R_{in}) of the inner accretion disc obtained from the spectral fitting with the model combination - constant × tbabs(diskbb + relxillNS) showed the source to be in its soft spectral state during the observations. The inclination angle (θ) of the source was estimated to be between 19° and 33° and the inner disc radius (R_{in}) was found to be 17.4 km. Assuming the case of magnetic truncation of accretion disc, the upper limits for the magnetic dipole moment (μ) and the magnetic field strength (B) at the poles of the neutron star in the system were found to be 5.78×10^{26} G cm^3 and 8.23×10^8 G, respectively, for kA = 1. This work has been done in collaboration with Neal Titus Thomas, Khushi Jirawala, and S. G. Bubbly.

AstroSat's view of 4U 1735-44: spectral, temporal, and type I X-ray burst studies

This study utilizes the simultaneous broad-band observations of 4U 1735-44 from AstroSat, offering enhanced spectral and temporal resolution, to investigate its spectral properties, temporal behaviour, and burst characteristics. Spectral, type I X-ray burst, and temporal analyses on 4U 1735-44 were performed using AstroSat/Soft X-ray Telescope and Large Area X-ray Proportional Counter (LAXPC) observations. The hardness-intensity diagram from LAXPC-20 showed a positive correlation between hardness and intensity, with a pattern resembling the banana branch typical of atoll sources. Spectral analysis carried out in the 0.7-20.0 keV energy range, using the model combination – constant×tbabs (nthcomp+diskbb+bbodyrad), suggested a cool accretion disc truncated at a large distance from the neutron star in the system. Time-resolved spectral studies of two type I X-ray bursts detected from the source revealed evidence of photospheric radius expansion, allowing for an estimation of the source distance. Temporal analysis showed the presence of low-frequency quasi-periodic oscillation at ∼69 Hz (3.3σ significance with more than 99 per cent confidence) and

prominent noise features below 30 Hz. This work has been done in collaboration with S. Lavanya, Neal Titus Thomas, and S. G. Bubbly.

Sarbari Guha

Memory effect of gravitational wave pulses in PP-wave spacetimes

In this paper, we study the gravitational memory effect in pp-wave spacetimes due to the passage of a pulse having the form of a ramp profile through this spacetime.Wehave analyzed the effect of this pulse on the evolution of nearby geodesics, and have determined analytical solutions of the geodesic equations in the Brinkmann coordinates.Wehave also examined the changes in the separation between a pair of geodesics and their velocity profiles. The separation (along x or y-direction) increases monotonically from an initial constant value. In contrast, the relative velocity grows from zero and settles to a final non-zero constant value. These resulting changes are retained as memory after the pulse dies out. The nature of this memory is similar to that determined by earlier workers using Gaussian, square, and other pulse profiles, thereby validating the universality of gravitational wave memory. This study has been done in collaboration with Sucheta Datta .

Arrow of time and gravitational entropy in collapse

We investigate the status of the gravitational arrow of time in the case of a spherical collapse of a fluid that conducts heat and radiates energy. In particular, we examine the results obtained by W. B. Bonnor in his 1985 paper where he found that the gravitational arrow of time was opposite to the thermodynamic arrow of time. The measure of gravitational epoch function P used by Bonnor was given by the ratio of the Weyl square to the Ricci square. In this paper, we have assumed the measure of gravitational entropy (GE) P_1 to be given by the ratio of the Weyl scalar to the Kretschmann scalar. Our analysis indicates that Bonnor's result seems to be validated, i.e. the gravitational arrow and the thermodynamic arrow of time point in opposite directions. This strengthens the opinion that the Weyl proposal of GE applies only to the Universe as a whole (provided that we exclude the white holes). This work has been done in collaboration Samarjit Chakraborty, Sunil D Maharaj, and Rituparno Goswami.

Mamta Gulati

Galactic magnetic field and spiral arms against gas quenching due to Ram pressure

Interaction between the intracluster medium (ICM) and the interstellar medium (ISM) plays a crucial role in galaxy evolution. Surveys of galaxy clusters have shown that ram pressure stripping (RPS) is a dominant mechanism that removes the cold gas reservoir from cluster galaxies. We extend the analytical model for ram pressure stripping by Singh et al. (2019) to include asymmetries in the disc, such as spiral arms and regular magnetic fields along the spiral arms. Non-thermal pressure from magnetic fields acts against the ram pressure and leads to greater gas retention in galaxies. Our analytical modelling of spiral galaxies with magnetic fields shows that a strong magnetic field, with a strength of $10^{-5}\,G$, significantly enhances gas retention at the centre of a galaxy as it approaches the core of a cluster, thereby suppressing the stripping rates. We find that magnetic fields stronger than $10^{-6}\,G$ are critical for retaining gas all the way to the cluster centre. While both magnetic fields and galaxy mass contribute to the retention of gas, the influence of magnetic fields is particularly significant, especially in typical spiral galaxies where unusually high masses are not present. Our results may help in explaining why gas-rich galaxies can still be observed in dense cluster environments despite the strong stripping forces. This work has been done in collaboration with Meenu Prajapati.

Three-dimensional stellar orbits due to off-centered dark matter halo at the center of the disc galaxies

Stellar orbits and the evolution of galaxies are intertwined processes that have long-term implications on each other. This paper studies how stellar orbits at the galaxy's central region are disturbed by an asymmetric dark matter halo potential. Evidence from the observations and simulations in the Milky Way type galaxy suggests that the center of the dark matter halo could be off-centered by a few parsecs concerning the center of the core. The equations of motion of stars in the core of galaxies are expressed in terms of three-dimensional perturbed potential arising from the offset halo. The central region's azimuthal variation in the effective potential is obtained and the first-order epicyclic theory is used to solve for the orbits. The magnitude of this perturbation potential grows at small radii and exhibits $m = 1$ azimuthal fluctuations. In the central region, within 3 kpc radius, even a small halo

offset of 300 pc can cause a surprisingly strong spatial and kinematical lopsidedness. A planar orbit, initially assumed to be in disc plane, tends to leave the plane giving rise to non-planar configuration. Furthermore, as long as the halo offset persists, the central region will stay lopsided. The dark matter halo would significantly impact the dynamic development of this region and could help fuel the active galactic nucleus. This work has been done in collaboration with Meenu Prajapati.

Prabir Kumar Haldar

Analytical model of low-mass strange stars using Tolman space-time in (2+1) dimension

The low-mass strange stars are hard to explain. In this paper, we have modelled these low-mass strange stars using the Tolman lV metric in (2+1) dimensions. We found that the cause of the lower mass of the strange stars in our model is the presence of attractive or positive anisotropic force. We have also found that the cosmological constant has a significant role in the mass-radius relationship of the stars. We have used our model to predict the radius of a few low-mass strange stars. Our approach is helpful to predict the crucial parameters of the low-mass strange stars. This work has been done in collaboration with T Kundu, M Murshid, and M Kalam.

Priya Hasan & Syed Najamul Hasan

Membership determination in open clusters using the DBSCAN Clustering Algorithm

The unprecedented precision of Gaia has led to a paradigm shift in membership determination of open clusters where a variety of machine learning (ML) models can be employed. In this paper, we apply the unsupervised Gaussian Mixture Model (GMM) to a sample of thirteen clusters with varying ages ($log\ t \approx 6.38$-9.64) and distances (441-5183 pc) from Gaia DR3 data to determine membership. We use ASteca to determine parameters for the clusters from our revised membership data. We define a quantifiable metric Modified Silhouette Score (MSS) to evaluate its performance. We study the dependence of MSS on age, distance, extinction, galactic latitude and longitude, and other parameters to find the particular cases when GMM seems to be more efficient than other methods. We compared GMM for nine clusters with varying ages but we did not find any significant differences between GMM performance for younger and older clusters. But we found a moderate correlation between GMM performance and the cluster distance, where GMM works better for closer clusters. We find that GMM does not work very well for clusters at distances larger than 3 kpc. This work has been done in collaboration with Mudasir Raja, Md Mahmudunnobe, Md Saifuddin.

Gaps in the Main-Sequence of Star Cluster Hertzsprung–Russell Diagram

The presence of gaps or regions of small numbers of stars in the main sequence of the Hertzsprung Russell Diagram (HRD) of star clusters has been reported in literature. This is interesting and significant as it could be related to star formation and/or rapid evolution or instabilities. In this paper, using Gaia DR3 photometry and confirmed membership data, we explore the HRD of nine open clusters with reported gaps, identify them and assess their importance and spectral types.

Golam Mortuza Hossain

Probing the equation of state of neutron stars using neutrino oscillations

We study the phenomena of neutrino oscillations and flavor mixing by incorporating the gravitational effects through the Dirac equation in curved spacetime inside a spherically symmetric star. We show that the flavor transition probabilities of the neutrinos depend on the interior spacetime metric as they propagate out of the star. As a consequence, we show that one could distinguish between different possible equation of states of nuclear matter even for an isolated neutron star if one could determine the flavor composition of emitted neutrinos near the stellar surface. This work has been done in collaboration with S. Bandyopadhyay.

Joe Jacob

Unveiling the Bulge-Disc Structure, AGN Feedback, and Baryon Landscape in a Massive Spiral Galaxy with Mpc-Scale Radio Jets

This study delves into the bulge-disc components and stellar mass distribution in the fast-rotating, highly massive spiral galaxy 2MASX∼J23453268-0449256, distinguished by extraordinary radio jets extending to Mpc scales. Using high-resolution multi-wavelength Hubble Space Telescope (HST) observations and multi-parameter panchromatic spectral energy distribution (SED) fitting, we derive estimates for

the star formation rate, total baryonic mass in stars, and warm dust properties. Our findings, validated at a spatial resolution of approximately 100 pc, reveal a pseudo-bulge rather than a classical bulge and a small nuclear bar and resonant ring, challenging conventional models of galaxy formation. Additionally, the lack of tidal debris and the highly symmetric spiral arms within a rotationally supported stellar disc indicate a tranquil coevolution of the galactic disc and its supermassive black hole (SMBH). Significantly, the galaxy exhibits suppressed star formation in its center, potentially influenced by feedback from the central accreting SMBH with powerful radio jets. Detailed multi-wavelength studies of potential star-forming gas disclose that, while hot X-ray gas cools down in the galaxy's halo, new stars do not form in the center, likely due to feedback effects. This study raises questions about the efficient fueling and sustained collimated jet ejection activity in J2345-0449, underscoring the imperative need for a comprehensive understanding of its central black hole engine properties, which are presently lacking. The exceptional rarity of galaxies like 2MASX∼J23453268-0449256 presents intriguing challenges in unraveling the physical processes responsible for their unique characteristics. This work has been done in collaboration with Joydeep Bagchi, Shankar Ray, Suraj Dhiwar,and Pratik Dabhade et al.

European VLBI Network observations of the peculiar radio source 4C 35.06 overlapping with a compact group of nine galaxies

Context. According to the hierarchical structure formation model, brightest cluster galaxies (BCGs) evolve into the most luminous and massive galaxies in the Universe through multiple merger events. The peculiar radio source 4C 35.06 is located at the core of the galaxy cluster Abell 407, overlapping with a compact group of nine galaxies. Low-frequency radio observations have revealed a helical, steep-spectrum, kiloparsec-scale jet structure and inner lobes with less steep spectra, compatible with a recurring active galactic nucleus (AGN) activity scenario. However, the host galaxy of the AGN responsible for the detected radio emission remained unclear. Aims. We aim to identify the host of 4C 35.06 by studying the object at high angular resolution and thereby confirm the recurrent AGN activity scenario. Methods. To reveal the host of the radio source, we carried out very long baseline interferometry (VLBI) observations with the European VLBI Network of the nine galaxies in the group at 1.7 and 4.9 GHz. Results. We detected compact radio emission from an AGN located between the two inner lobes at both observing frequencies. In addition, we detected another galaxy at 1.7 GHz, whose position appears more consistent with the principal jet axis and is located closer to the low-frequency radio peak of 4C 35.06. The presence of another radio-loud AGN in the nonet sheds new light on the BCG formation and provides an alternative scenario in which not just one but two AGNs are responsible for the complex large-scale radio structure. This work has been done in collaboration with Patrik Milan Veres, Krisztina Eva Gabanyi, Sandor Frey, Zsolt Paragi, Tao An, Joydeep Bagchi et al.

Chetna Jain

The 2021 outburst of 2S 1417-624 revisited with AstroSat

This work presents the first ever broadband (0.7-25.0 keV) timing and spectral analysis of Be-HMXB 2S 1417-624 during its 2021 outburst. Using AstroSat observations, coherent pulsations at ∼17.36633 s (MJD 59239.082) were detected in 0.7-7.0 keV SXT and 3.0-25.0 keV LAXPC data. The pulse profile was dual peaked at all energies, with the relative intensity of the main peak increasing with energy. The peaks in the SXT profiles were broad and comprised of several mini-structures. The LAXPC profiles were relatively smooth and had higher pulsed fractions, which increased with energy. The SXT+LAXPC simultaneous energy spectrum is well described by an absorbed power-law with exponential cut-off, a ∼1.6 keV black body component, and a 6.47 keV emission line. A model comprising of an absorbed power law with high energy cut-off plus a partial covering absorber and Gaussian emission line fits the spectrum quite well. These results have been compared with timing and spectral features during the previous outbursts of this transient pulsar.

Timing analysis of Be/X-ray transient 4U 0115+63 during Type II outburst of 2023 using NuSTAR observations

In this paper, we present the timing analysis of high mass X-ray binary 4U 0115+63 during its Type II outburst of March 2023 using two NuSTAR observations. The first observation was made near the peak of the outburst, while the second observation was made near the end of declining phase. During the first

observation, 3-79 keV coherent pulsations at 3.61456(4) s (at MJD 60044.003) were detected. During the second observation, 3-68 keV coherent pulsations at 3.61309(1) s (at MJD 60060.732) were detected, thereby indicating a secular spin up of $-1.02(3) \times 10^{-9} ss^{-1}$. During these observations, the pulse profile was dual peaked with the relative intensity of minor peak reducing with energy. The main peak was narrower at low energies and it broadened as energy increased. The pulsed fraction showed a positive correlation with energy, along with local maxima close to the cyclotron absorption features. Quasi periodic oscillations were also detected up to 20 keV. Broad ∼12.4 mHz and ∼58.3 mHz QPOs were detected near the peak of the outburst and towards its end, QPOs centered at ∼2.3 mHz, ∼8.4 mHz and ∼66.5 mHz were detected. We discuss the implication of these results on our understanding of accretion mechanism during outbursts. This work has been done in collaboration with Prince Sharma and Anjan Dutta.

Deepak Jain

Unveiling the Impact of Degeneracy in an Isolated Two-Level System: An Undergraduate Problem

The study of isolated two-level systems (e.g. paramagnetic salt) is an integral part of every statistical mechanics coursework at undergraduate level. However, the thermodynamical properties of such a system are usually explained with a very brief introduction to the degeneracy associated with the levels. Therefore, in this study, we revisited the macroscopic properties such as entropy, temperature and specific heat of a degenerate two-level system (both symmetric and asymmetric cases). We believe that this simple and analytic calculation may give very useful insight to undergraduate students. This work has been done in collaboration with Anuradha Gupta.

Nur Jaman

CMB constraints on natural inflation with gauge field production

The natural inflation model with a periodic cosine potential is ruled out by recent Planck 2018 data for the decay constant $f \lesssim 5.5\ M_{\rm Pl}$. If the Planck data is combined with the BICEP Keck array and BAO data, the model is excluded (at 2-σ) for all values of f. In this context, we revisit the model when the pseudoscalar inflation ϕ is coupled with a gauge field via a coupling of the form $\frac{\alpha}{f}\phi F\tilde{F}$, where $F(\tilde{F})$ denotes the gauge field (dual) strength tensor, and α is the coupling constant. The back-reactions associated with the gauge field production during the later stages of inflation extend the duration of inflation. We numerically evaluate the dynamics of the fields while neglecting the effects due to the perturbations in the inflaton field. It allows us to determine the scalar and tensor power spectra leading to the calculations of observables at the Cosmic Microwave Background (CMB) scales. We find that the natural inflation model survives the test of the latest data only for a certain range of the coupling constant α. Our analysis shows that the latest constraints coming from the scalar spectral index are more stringent than the ones arising from the non-gaussianities and the running of the scalar spectrum. This leads to lower and upper bounds on ξ_*, the parameter that controls the growth of the gauge field. This work has been done in collaboration with Khursid Alam, Koushik Dutta.

Charles Jose

Understanding the radio luminosity function of star-forming galaxies and its cosmological evolution

We explore the redshift evolution of the radio luminosity function (RLF) of star-forming galaxies using Galform, a semi-analytic model of galaxy formation and a dynamo model of the magnetic field evolving in a galaxy. Assuming energy equipartition between the magnetic field and cosmic rays, we derive the synchrotron luminosity of each sample galaxy. In a model where the turbulent speed is correlated with the star formation rate, the RLF is in fair agreement with observations in the redshift range $0 \leq z \leq 2$. At larger redshifts, the structure of galaxies, their interstellar matter and turbulence appear to be rather different from those at $z \lesssim 2$, so that the turbulence and magnetic field models applicable at low redshifts become inadequate. The strong redshift evolution of the RLF at $0 \leq z \leq 2$ can be attributed to an increased number, at high redshift, of galaxies with large disc volumes and strong magnetic fields. On the other hand, in models where the turbulent speed is a constant or an explicit function of z, the observed redshift evolution of the RLF is poorly captured. The evolution of the interstellar turbulence and outflow parameters appear to be major (but not the only) drivers of the RLF changes. We find that both the small- and large-scale magnetic fields contribute to the RLF but the small-scale field dominates at high

redshifts. Polarisation observations will therefore be important to distinguish these two components and understand better the evolution of galaxies and their nonthermal constituents. This work has been done in collaboration with Luke Chamandy, Anvar Shukurov, Kandaswamy Subramanian, Luiz Felippe S Rodrigues, and Carlton M Baugh.

Probing Environmental Dependence of High-Redshift Galaxy Properties with the Marked Correlation Function

In hierarchical structure formation, correlations between galaxy properties and their environments reveal important clues about galaxy evolution, emphasizing the importance of measuring these relationships. We probe the environmental dependence of Lyman-break galaxy (LBG) properties in the redshift range of 3 to 5 using marked correlation function statistics with galaxy samples from the Hyper Suprime-Cam Subaru Strategic Program and the Canada-France-Hawaii Telescope U-band surveys. We find that the UV magnitude and color of magnitude-selected LBG samples are strongly correlated with their environment, making these properties effective tracers of it. In contrast, the star formation rate and stellar mass of LBGs exhibit a weak environmental dependence. For UV magnitudes and color, the correlation is stronger in brighter galaxy samples across all redshifts and extends to scales far beyond the size of typical dark matter halos. This suggests that within a given sample, LBGs with high UV magnitudes or colors are more likely to form pairs at these scales than predicted by the two-point angular correlation function. Moreover, the amplitude of the marked correlation function is generally higher for LBG samples compared to that of $z \sim 0$ galaxies from previous studies. We also find that for LBG samples selected by the same absolute threshold magnitude or average halo mass, the correlation between UV magnitudes and the environment generally becomes more pronounced as the redshift decreases. On the other hand, for samples with the same effective large-scale bias at $z \sim 4$ and 5, the marked correlation functions are similar on large scales. This work has been done in collaboration with Emy Mons.

Nur Jaman

CMB constraints on natural inflation with gauge field production

The natural inflation model with a periodic cosine potential is ruled out by recent Planck 2018 data for the decay constant $f \lesssim 5.5\ M_{\rm Pl}$. If the Planck data is combined with the BICEP Keck array and BAO data, the model is excluded (at 2-σ) for all values of f. In this context, we revisit the model when the pseudoscalar inflation ϕ is coupled with a gauge field via a coupling of the form $\frac{\alpha}{f}\phi F\tilde{F}$, where $F(\tilde{F})$ denotes the gauge field (dual) strength tensor, and α is the coupling constant. The back-reactions associated with the gauge field production during the later stages of inflation extend the duration of inflation. We numerically evaluate the dynamics of the fields while neglecting the effects due to the perturbations in the inflaton field. It allows us to determine the scalar and tensor power spectra leading to the calculations of observables at the Cosmic Microwave Background (CMB) scales. We find that the natural inflation model survives the test of the latest data only for a certain range of the coupling constant α. Our analysis shows that the latest constraints coming from the scalar spectral index are more stringent than the ones arising from the non-gaussianities and the running of the scalar spectrum. This leads to lower and upper bounds on ξ_*, the parameter that controls the growth of the gauge field. This work has been done in collaboration with Khursid Alam, and Koushik Dutta.

Jessy Jose

Twins in diversity: understanding circumstellar disc evolution in the twin clusters of W5 complex

Young star-forming regions in massive environments are ideal test beds to study the influence of surroundings on the evolution of disks around low-mass stars. We explore two distant young clusters, IC 1848-East and West located in the massive W5 complex. These clusters are unique due to their similar (distance, age, and extinction) yet distinct (stellar density and FUV radiation fields) physical properties. We use deep multi-band photometry in optical, near-IR, and mid-IR wavelengths complete down to the substellar limit in at least five bands. We trace the spectral energy distribution of the sources to identify the young pre-main sequence members in the region and derive their physical parameters. The disk fraction for the East and West clusters down to 0.1 $M_\odot$ was found to be $\sim$27$\pm$2% ($N_{\rm disk}$=184, $N_{\rm diskless}$=492) and $\sim$17$\pm$1% ($N_{\rm disk}$=173, $N_{\rm diskless}$=814), respectively. While no spatial variation in the disk fraction is observed, these values are lower than those in other nearby young clusters. Investigating the cause of this decrease, we find a correlation with the intense feedback from

massive stars throughout the cluster area. We also identified the disk sources undergoing accretion and observed the mass accretion rates to exhibit a positive linear relationship with the stellar host mass and an inverse relationship with stellar age. Our findings suggest that the environment significantly influences the dissipation of disks in both clusters. These distant clusters, characterized by their unique attributes, can serve as templates for future studies in outer galaxy regions, offering insights into the influence of feedback mechanisms on star and planetary formation. This work has been done in collaboration with Belinda Damian,Swagat R. Das, Saumya Gupta, et al.

Does Metallicity Affect the Protoplanetary Disk Fraction? Answers from the Outer Milky Way

The role of metallicity in shaping protoplanetary disk evolution remains poorly comprehended. This study analyzes the disk fraction of 10 young (0.9-2.1 Myr) and low-metallicity (0.34-0.83 $Z_{\odot}$) clusters located in the outer Milky Way with Galactocentric distances between 10 and 13 kpc. Using JHK data obtained from UKIDSS, the calculated disk fraction values for low-mass stars (0.2-2 $M_{\odot}$) ranged from 42% to 7%. To enhance the statistical reliability of our analysis, eight additional low-metallicity clusters are sourced from previous studies with metallicity range 0.25-0.85 $Z_{\odot}$ along with our sample, resulting in a total of 18 regions with low-metallicity. We find that low-metallicity clusters exhibit on average 2.6 ± 0.2 times lower disk fraction compared to solar-metallicity clusters in all the age bins we have. Within the age range we can probe, our study does not find evidence of faster disk decay in sub-solar metallicity regions compared to solar-metallicity regions. Furthermore, we observe a positive correlation between cluster disk fraction and metallicity for two different age groups of $0.3 - 1.4$ and $1.4 - 2.5$ Myr. We emphasize that both cluster age and metallicity significantly affect the fraction of stars with evidence of inner disks. This work has been done in collaboration with Sudeshna Patra, and Neal J. Evans II

Minu Joy

Primordial blackhole formation: exploring chaotic potential with a sharp step via the GLMS perspective

A sharp step on a chaotic potential can enhance primordial curvature fluctuations on smaller scales to the $\mathcal{O}(10^{-2})$ to form primordial black holes (PBHs). The present study discusses an inflationary potential with a sharp step that results in the formation of PBHs in four distinct mass ranges. Also this inflationary model allows the separate consideration of observable parameters n_s and r on the CMB scale from the physics at small scales, where PBHs formation occur. In this work we computed the fractional abundance of PBHs (f_{PBH}) using the GLMS approximation of peak theory and also the Press-Schechter (PS) formalism. In the two typical mass windows, $10^{-13}M_{\odot}$ and $10^{-11}M_{\odot}$, f_{PBH} calculated using the GLMS approximation is nearly equal to 1 and that calculated via PS is of 10^{-3}. In the other two mass windows $1M_{\odot}$ and $6M_{\odot}$, f_{PBH} obtained using GLMS approximation is 0.01 and 0.001 respectively, while f_{PBH} calculated via PS formalism yields 10^{-5} and 10^{-6}. The results obtained via GLMS approximation are found to be consistent with observational constraints. A comparative analysis of f_{PBH} obtained using the GLMS perspective and the PS formalism is also included. This work is done in collaboration with Rinsy Thomas and Jobil Thomas.

Mehedi Kalam

Gravastar in the framework of Loop Quantum Cosmology

In this paper, we attempt to construct a regular gravastar model using the UV corrected framework of Loop Quantum Cosmology. We find that a stable gravastar model can be constructed with a number of unique features: (i) no thin shell approximation needs to be invoked to obtain solutions in the shell which can be considered to be of a finite thickness, (ii) the central singularity of a self-gravitating object can be averted by a bounce mechanism, such that the interior density of the gravastar reaches a maximum critical density and cannot be raised further due to an operative repulsive force, (iii) the inherent isotropy of the effective fluid description does not prevent the formation of a stable gravastar, and anisotropic pressures is not an essential requirement. This work has been done in collaboration with Shounak Ghosh, and Rikpratik Sengupta.

Neutron stars in f(R,T) theory: slow rotation approximation

In this paper, we study the slowly rotating neutron stars in $f(R,T)$ gravity based on Hartle-Thorne formalism. We first consider the simplest matter-geometry coupled modified gravity, namely $f(R,T) = R + 2\chi T$. We compute the mass, radius, moment of inertia, change in

radius, and binding energy due to rotation, eccentricity, quadrupole moment, and the tidal love number. The quantities, which are of the second order in angular velocity, like change in radius and binding energy due to rotation, eccentricity, and quadrupole moment, deviate more from their corresponding general relativistic counterparts in lighter neutron stars than heavier ones. Whereas the moment of inertia, which is of the first order in angular velocity, in $f(R,T) = R+2\chi T$ modified gravity, barely diverges from the general relativistic one. The Equation of state-independent I-Love-Q relation retains in this $f(R,T)$ modified gravity, and it coincides with the general relativistic ones within less than one percent even for the maximum allowed coupling parameters. We also study the slowly rotating neutron star in $f(R,T) = R + \alpha R^2 + 2\chi T$ up to first order their angular velocity. We calculate the mass, radius, and moment of inertia of neutron stars in this modified gravity. The results show that the impact of the matter-geometric coupling parameter is greater on lighter neutron stars in both of these modified gravity models. This work has been done in collaboration with Masum Murshid.

Arun Kenath

Can Hubble tension be eased by invoking a finite range for gravity?

The estimation of the Hubble constant in the past few decades has increasingly become more accurate with the advancement of new techniques. However, its value seems to depend on the epoch at which the measurements are made. The Planck estimate of the Hubble constant from the observations of the cosmic microwave background radiation in the early universe is about 67 km/s/Mpc, whereas that obtained from the distance indicators at the current epoch is 73 km/s/Mpc. This discrepancy between the two groups of measurement is termed as the Hubble tension which has gained much attention in the past few decades with growing significance as measurements from both, the early and the late universe, studies continue to produce results with increasing precision. In this work, we propose a modification to gravity by considering a finite range gravitational field as an alternate explanation for this discrepancy in the value of the Hubble constant. This work has been done in collaboration with Louise Rebecca, C. Sivaram, and Dominic Sebastian.

Interacting Dark Energy and Its Implications for Unified Dark Sector

Alternative dark energy models were proposed to address the limitation of the standard concordance model. Though different phenomenological considerations of such models are widely studied, scenarios where they interact with each other remain unexplored. In this context, we study interacting dark energy scenarios (IDEs), incorporating alternative dark energy models. The three models that are considered in this study are time-varying Λ, Generalized Chaplygin Gas (GCG), and K-essence. Each model includes an interaction rate Γ to quantify energy density transfer between dark energy and matter. Among them, GCG coupled with an interaction term shows promising agreement with the observed TT power spectrum, particularly for $\ell < 70$, when Γ falls within a specific range. The K-essence model ($\Gamma \leq 0.1$) is more sensitive to Γ due to its non-canonical kinetic term, while GCG ($\Gamma \geq 1.02$) and the time-varying Λ ($\Gamma \leq 0.01$) models are less sensitive, as they involve different parameterizations. We then derive a general condition when the non-canonical scalar field ϕ (with a kinetic term X^n) interacts with GCG. This has not been investigated in general form before. We find that current observational constraints on IDEs suggest a unified scalar field with a balanced regime, where it mimics quintessence behavior at $n < 1$ and phantom behavior at $n > 1$. We outline a strong need to consider alternative explanations and fewer parameter dependencies while addressing potential interactions in the dark sector. This work has been done in collaboration with Pradosh Keshav MV.

Ram Kishor

Invariant manifolds of Lyapunov periodic orbits in the RCD solar sail problem with dipole secondary

Invariant manifolds of a periodic orbit are very important dynamical aspects to understand the quantitative as well as qualitative behaviour of non-linear phenomenon in a dynamical system. This paper presents the computation of invariant manifolds of Lyapunov periodic orbits near artificial equilibrium points (AEPs) $\vec{L_1}$ and $\vec{L_2}$ for a solar sail equipped with reflectivity control device (RCD) under the frame of circular restricted three body problem with dipole secondary. The families of Lyapunov periodic orbits near $\vec{L_1}$ and $\vec{L_2}$ points are obtained by continuation technique and then impacts of sail lightness number

β and dipole distance d of the dipole secondary are observed in the context of initial conditions and time period. It is noticed that in the presence of dipole secondary, the family of Lyapunov periodic orbits are unstable. Next, the stable and unstable branches of invariant manifolds of Lyapunov periodic orbits are computed under the influence of sail lightness number and dipole secondary and it is found that effect of and dipole distance d are negligible. These results will to the study about the construction of transfer trajectories and to execute the low-energy transfer. This work has been done in collaboration with Pulkit Gahlot.

Orbital analysis in generalised solar sail problem with Stokes drag effect

The study of orbits about the artificial equilibrium points of the solar sail problem (or satellite equipped with solar sail) is an important part for a mission design. This paper investigates about the motion of a solar sail in the presence of oblate primaries and Stokes drag effect. First, we have formulated solar sail problem and then determined the artificial equilibrium points (AEPs). It is found that due to Stokes drag, collinear AEPs do not exist but two non-collinear AEPs ($\vec{L_{4,5}}$) exist, which are asymptotically stable with respect to all values of oblateness (A_2) as well as dissipative constant (κ), whereas relative to sail lightness number (β) , these are asymptotically stable for the range $0 \leq \beta < 0.4102$. Again, the long as well as short periodic orbits are determined and impact of perturbing factors are observed by finding the amplitude, time period and phase of the respective orbits. Further, tadpole orbit of the solar sail near AEPs are computed and effect of perturbations are analysed on the basis of number of loops and its shape in the orbits. This work has been done in collaboration with Pulkit Gahlot.

Nagendra Kumar

Comparative study of solar rotation of transition region and corona using solar irradiance and radio flux

We study the temporal variation of solar rotation profiles based on solar irradiance at 93.5 nm and solar radio flux at 10.7 cm originating from the transition region and lower corona, respectively. The autocorrelation technique is used to calculate the period in periodic time series data. The sidereal rotation periods for normalized and detrended data are studied for 2011â€“2021. The sidereal rotation periods for solar irradiance and radio flux for 2011â€“2021 vary from 22.75 to 26.17 days and 19.42 to 28.14 days, respectively. The mean of the sidereal rotation periods for solar irradiance and radio flux are 24.76 and 23.76 days, respectively. The mean sidereal rotation period for solar irradiance is higher than the mean sidereal rotation period for solar radio flux. The sidereal rotation period for solar irradiance is greater than or equal to the sidereal rotation period for solar radio flux for almost all the years between 2011 and 2021. It is found that the lower corona rotates faster than the transition region during 2011-2021, i.e., the lower corona is found to be moving 4 % faster than the transition region during 2011-2021. We found a linear relationship between the normalized daily irradiance and radio flux with a correlation coefficient of 0.986. Using cross-correlation analysis, we investigated a phase relationship between solar irradiance and radio flux and found no time lag between solar irradiance and radio flux. This work has been done in collaboration with Avneesh Kumar and Hari Om Vats.

Performance assessment of 4D-VAR microphysics schemes in simulating the track and intensity of super cyclonic storm Amphan

The Four-Dimensional Variational (4DVar) data assimilation system of the Advanced Research Weather Research and Forecasting (WRF) model, developed by the international community dedicated to data assimilation research and operations, is customised to simulate the super cyclonic storm ″Amphan″ formed over the Bay of Bengal during May 16, 2020, to May 21, 2020. Five simulations are conducted using five different microphysics schemes namely, Kessler, Lin et al., WRF Single Moment 3-class (WSM3), WSM5, and WSM6 at a horizontal resolution of 18 km, keeping the Kain-Fritsch cumulus and the Yonsei University planetary boundary-layer scheme fixed. The model simulated features of ″Amphan″ are compared with observational data from the India Meteorological Department (IMD), the Global Precipitation Measurement mission (GPM), and the 5th generation European Centre for Medium-Range Weather Forecasts (ECMWF) Atmospheric Reanalysis (ERA-5) over the specified region. Among all the schemes, Lin et al. scheme shows track remarkably close to the observed track. Lin et al. (WSM5) scheme shows least along track (AT) error of 7.47 km at 24-h forecast length. Lin et al. shows least AT error of 5.8 km (28.12 km) for 48-h (72-h) forecast length. All schemes except Kessler and WSM3 show the spatial

distribution of maximum sustained wind (MSW) surrounding the eye of the cyclone which is similar with ERA5 data. All the schemes underestimate the 10m-MSW during the entire life of the storm. However, the Kessler scheme simulates higher 10m-MSW during 00 UTC 18 May to 12 UTC 19 May in comparison to other schemes and further the simulated MSW matches with IMD observation up to 06 UTC 20 May. The Kessler scheme overestimates the MSLP for the intensity level ESCS-VSCS-SCS-CS valid 09 UTC on 19 May to 00 UTC on 21 May and other schemes underestimate during this period. The analysis carried out with the Method for Object-Based Diagnostic Evaluation tool reveals that the Lin et al. (WSM6) scheme indicates enhanced forecast proficiency for accumulation valid 00 UTC 20 May (21 May) 2020. The analysis of vertically integrated moisture transport (VIMT) and vertically integrated moisture divergence (VIMD) suggests that the greater moisture transport is quite evident in Lin et al. scheme during the SuCS intensity level. Kessler scheme is efficient in simulating warm-rain process and high intensity storm. This work has been done in collaboration with Arun Kumar, Kanak Lata Xalxo, Sushil Kumar, Biranchi Kumar Mahala and Ashish Routray.

Rajesh Kumar

Anisotropic Durgapal-Fuloria compact stars in $f(R)$ Gravity

This study presented a new exact solution for anisotropic compact stellar objects within the framework of () = $+\alpha 2$ gravity. In this context, the Durgapal-Fuloria metric potential has been employed to solve the field equation derived for () theory. Furthermore, we have derived the generalized Darmois-Israel junction condition necessary for seamlessly connecting the interior region to the Schwarzschild exterior metric across the boundary hypersurface of the star in the context of () gravity, and the interior solution is matched with the Schwarzschild exterior metric over the bounding surface of a compact star. These junction conditions stipulate that the pressure must not be zero at the boundary and should be proportional to the non-linear term of () gravity, a crucial aspect often overlooked by many researchers when investigating compact stellar models. Additionally, we derived the values of these parameters by using observational data of various compact stars (CSs), namely $HerX-1, SAXJ1808.4-3658, SMCX-1, LMCX-4, CenX-3, 4U1820-30, PSRJ1903+327, 4U1608-52, VelaX-1$, and $PSRJ1416-2230$. This approach enables us to investigate the comprehensive analysis of solutions numerically and graphically. We conducted various physical tests, including gradient of energy density and pressures, anisotropy, stability, equilibrium conditions, energy-density constraints, mass function compactness, redshift, and adiabatic index, to assess the feasibility of our models. Our findings demonstrate the consistent behavior of our models provides a satisfactory physical situation as far as the observational results are confirmed.This work is done in collaboration with S.K. Maurya, A. Errehymy, G. Mustafa, Abdel-Haleem Abdel-Aty, H.I. Alrebdi, and Mona Mahmoud.

Constructing stellar solutions with spherical symmetry through quadratic anisotropy in $f(Q)$ gravity

This article examines anisotropic models to characterize compact stars (CSs) in the context of modified $f(Q)$ gravity theory. To achieve this, we employ the linear functional form $f(Q) = \alpha Q + \beta$. A physically meaningful metric potential g_{rr} is considered, and a quadratic form of anisotropy is utilized to solve the Einstein field equations in closed form. This class of solutions is then applied to characterize observed pulsars from various perspectives. In the scope of $f(Q)$ gravity, we address the Darmois-Israel junction requirements to guarantee a smooth matching of the inner metric with the external metric (Schwarzschild (Anti-) deSitter solution) at the boundary hypersurface. By applying these junction conditions, we determine the model parameters involved in the solutions. Additionally, this study evaluates the physical viability and dynamical stability of the solution for different values of the f(Q)-parameter Î± within the compact star (CS). The massâ€“radius relationships associated with observational constraints are analyzed for several compact stars, including $VelaX-1, PSRJ1614-2230$, and $PSR0952-0607$. The investigation indicates that the estimated radius of the compact object $PSRJ0952-0607$, with mass $2.35\pm0.17M\odot$, is around $15.79^{+0.05}_{-0.09}$ km for a particular parameter value of $\alpha = 2.0$, and the moment of inertia for the de Sitter space is determined as $4.31x1045\ g\ cm^2$.The $I\hat{}'M$ curves hows greater sensitivity to the stiffness of the equation of state than the $M\hat{}'R$ curve, reinforcing our conclusion about the $I\hat{}'M$ frameworkâ€™s responsiveness.Finally, we predicted the corresponding radii and moments of inertia for various values of Î± based on the $M\hat{}'R$ and $M\hat{}'I$ curves. This

work is done in collaboration with S.K. Maurya, A. Errehymy, A. Jaiswal, K. Myrzakulov,

R. K. Sunil Kumar

Adapting to Noise in Forensic Speaker Verification Using GMM-UBM I-Vector Method in High-Noise Backgrounds

The performance of the GMM-UBM-I vector in a forensic speaker verification system has been examined in the context of noisy speech samples. This analysis utilised both Mel-frequency cepstral coefficients (MFCC) and MFCCs generated from auto-correlated speech signals. The noisy signal's autocorrelation coefficients are concentrated around the lower lag, whereas the autocorrelation coefficients near the higher lag are very small. Thus, in addition to retaining the periodic nature, autocorrelation-based MFCC is also robust for analyzing speech signals in intense background noise. The performance of MFCC and auto-correlated MFCC depends heavily on the quality of the sample. It works best with data that is free of noise but suffers when used on real-world examples with noisy data. The experiment on speaker verification for forensic purposes involved the addition of White Gaussian Noise, Red Noise, and Pink Noise, with a Signal-to-Noise Ratio (SNR) range spanning from 20 dB to+20 dB. The performance of both methods was affected drastically in all cases, but autocorrelation-based MFCC gave better results than MFCC. Thus, autocorrelation-based MFCC is a valuable method for robust feature extraction when compared with MFCC for speaker verification purposes in intense background noise. The verification accuracy in our method is improved even in very high noise levels (20 dB) than the reported research work. This work has been done in collaboration with K. V. Aljinu Khadar, and N. S. Sreekanth.

Multi Speaker Activity Detection Using Spectral Centroids

In recent years, there has been a notable increase in the demand for reliable and effective methods in the domain of audio processing, specifically for the purpose of analysing complex acoustic surroundings. Multi-Speaker Activity Detection (MSAD) is a fundamental task in this domain that entails the detection and classification of multiple speakers in an audio recording. In this work, we propose a novel approach for MSAD based on the concept of Spectral Centroids. Spectral Centroids provide valuable insights into the spectral characteristics of audio signals and have been widely used for tasks such as music genre classification and instrument recognition. In our work, we utilise spectral centroid data to create an efficient MSAD system. The performance of our proposed MSAD system is assessed using a broad dataset that encompasses a range of auditory situations and speaker configurations. The utilisation of gender-specific threshold values and the inclusion of the spectral centroid characteristic in the process of multi-speaker activity detection exhibit potential in effectively ascertaining the number of speakers in simultaneous voice recordings. The results obtained for male and female test sets indicate the effectiveness of this approach in differentiating between speakers of different genders. Continued research and refinement of the spectral centroid-based method could lead to advancements in multi-speaker activity detection systems, enabling applications such as speaker diarization and speech separation in complex audio environments. This work has been done in collaboration with K. V. Aljinu Khadar, P. K. Neeraj Krishnan, and V. V. Sameer.

Sanjay Kumar

Exploring the generation and annihilation of three-dimensional nulls through MHD simulations in initially chaotic magnetic field devoid of null

Three-dimensional (3D) magnetic nulls are abundant in the solar atmosphere, as has been firmly established through contemporary observations. They are established to be important magnetic structures in, for example, jets and circular ribbon flares. Although simulations and extrapolations support this, the mechanisms behind 3D null generation remain an open question. Recent magnetohydrodynamic simulations demonstrated magnetic reconnections to be responsible for both generating and annihilating 3D nulls. However, these simulations began with initial magnetic fields already supporting preexisting nulls, raising the question of whether magnetic reconnection can create nulls in fields initially devoid of them. Previously, this question was briefly explored in a simulation with an initial chaotic magnetic field. However, the study failed to precisely identify locations, topological degrees, and natures (spiral or radial) of nulls, and it approximated magnetic reconnection without tracking the magnetic field lines in time. In this paper, these

findings are revisited in light of recent advancements and tools used to locate and trace nulls, along with the tracing of field lines, through which the concept of generation/ annihilation of 3D nulls from chaotic fields is established in a precise manner. This work has been done in collaboration with Yogesh Kumar Maurya, Ramit Bhattacharyya, David I. Pontin.

Data-Constrained Magnetohydrodynamics Simulation of a Confined X-class Flare in NOAA Active Region 11166

n this paper, we present a magnetohydrodynamics simulation of NOAA active region 11166 to understand the origin of a confined X-class flare that peaked at 23:23 UT on 2011 March 9. The simulation is initiated with a magnetic field extrapolated from the corresponding photospheric magnetogram using a non-force-free-field extrapolation technique. Importantly, the initial magnetic configuration identifies three-dimensional (3D) magnetic nulls and quasi-separatrix layers (QSLs), which nearly agree with the bright structures appeared in multi-wavelength observations. The Lorentz force associated with the extrapolated field self-consistently generates the dynamics that leads to the magnetic reconnections at the 3D nulls and the QSLs. These reconnections are found to contribute to the pre-flare activities and, ultimately, lead to the development of the flare ribbons. Notably, the anchored spine of the 3D null and the complete absence of flux rope in the flaring region are congruent with the confined nature of the flare. Furthermore, the simulation also suggests the role of reconnections at the 3D null with an open spine in the onset of a jet away from the flaring site.This work has been done in collaboration with Pawan Kumar, Sadashiv, Sushree S. Nayak, Satyam Agarwal,and Ramesh Chandra et al.

Badam Singh Kushvah

Analysis of albedo and disc effects in the generalized restricted four-body problem

This manuscript explores the Generalized Restricted Four-Body Problem within the context of radiation pressure, the albedo effect, oblateness, and a disc-like structure that orbits around the primary bodies. We have considered that one of the primaries is a bigger primary, and the rest of the two smaller primaries are of equal masses, in which one of the smaller primaries is considered as a black body. Moreover, the perturbing forces by the effect of radiation pressure and oblateness are considered in the bigger primary. The effect of albedo and oblateness due to the second smaller primary is also taken into count. This study yields nine equilibrium points corresponding to various parameter values, including three collinear and six non-collinear equilibria. We conduct an analysis of the equilibrium points, their linear stability, and the motion around them. In the context of the considered parameter set, certain collinear equilibrium points exhibit stability, while others are unstable. Additionally, most of the non-collinear equilibrium points display linear stability. We also investigate variations in Jacobis constant and the positions of existing equilibrium points caused by the albedo and disc effects. It is found that the value of Jacobi constant C_{Lj} decreases with an increase in the mass parameter μ at the collinear points, which results in an expansion in the prohibited region. The inhibited zone of motion of the infinitesimal body is shown for different sets of parameters. This work has been done in collaboration with Manoj Kumar, and Ravi Kumar Verma.

Temporal Trends in Asteroid Behavior: A Machine Learning and N-Body Integration Approach

Asteroids pose significant threats to Earth, necessitating early detection for potential deflection. Leveraging machine learning (ML), we classify asteroids into Near-Earth Asteroids (particularly Atens, Amors, Apollos, and Apoheles) and Non Near-Earth Asteroids, further categorizing them based on hazard potential. Training the seven models on a comprehensive dataset of 4687 asteroids, we achieve high accuracy in prediction. The predictive capability of these models is critical for informed decision-making in planetary defense strategies. We apply different regularization techniques to prevent overfitting and validate the models using a large unseen dataset. A rigorous long-term N-body integration spanning 1 million years is executed utilizing the Mercury N-body integrator to illuminate the evolution of asteroid properties over extended temporal scales. Following this integration process, the best-performing ML model is employed to classify asteroids based on their orbital characteristics and hazardous status respectively. Our findings highlight the effectiveness of ML in asteroid classification and prediction, paving the way for large-scale applications. By dividing a 1 million-year integration into intervals, we uncover temporal trends in asteroid behavior, revealing insights into hazard evolution and ejection patterns. Notably, initially, hazardous asteroids tend to transition to non-hazardous states over

time, elucidating key dynamics in planetary defense. We illustrate these findings through plotted graphs, providing valuable insights into asteroid dynamics. These insights are instrumental in advancing our understanding of long-term asteroid behavior, with significant implications for future research and planetary protection efforts. This work has been done in collaboration with Chetan Abhijnanam Bora,Gunda Chandra Mouli and Saleem Yousuf.

Vinjanampaty Madhurima

Investigating Hydrogen Bonding Interactions in Aniline-Acetone Binary Mixture through Molecular Dynamics Simulations

Binary liquid systems serve as valuable prototypes for comprehending biologically and chemically relevant properties of hydrogen bonds, revealing both noteworthy patterns and anomalies in their behaviour. Aniline, acetone and their binary mixtures with other liquids are used in various industrial processes, drug design, and as cleaning agents. This study is a molecular dynamics exploration of aniline and acetone binary mixture, over a concentration range of $9:1^{\smile}1:9$ for each component. The investigation includes employing techniques such as radial distribution function (RDF), coordination number calculation, hydrogen bond statistics, and graph theoretical analysis (GTA) through the NetworkX module in python, cluster analysis, Voronoi entropy calculation, interaction energy calculation and FTIR spectroscopy for all concentrations studied. The results uncover a compelling trend: a decrease in the number of hydrogen bonds as the concentration of acetone increases. Additionally, increased acetone concentration correlates positively with the breakdown of larger and more complex hydrogen-bonded structures, indicating the formation of small hydrogen-bond structures. This work has been done in collaboration with M. K. Ajmal Rahman, Abdulkareem U, and P. V. Swathi.

Nanoscale Wettability of Water-Alcohol Mixtures on Graphite Surface: Molecular Dynamics Study

The ability to predict and control surface wettability at the nanoscale is crucial and rapidly evolving, particularly in the fields of microfluidics and nanotechnology. Typically, the contact angle is measured in simulations by creating a liquid droplet on a solid surface, fitting a curve to the droplet's interface, and determining the angle at the triple-phase contact line. However, at the molecular level, the triple-phase contact line becomes ambiguous due to the continuous motion of molecules, making conventional measurements difficult. This study reports the molecular dynamics simulations to determine the contact angle of water mixed with four primary alcohols (RN-OH, where R = (CNH2N+1), N varies from 1 to 4) on a graphite substrate, using the Hautman and Klein method, which links the microscopic contact angle to the droplet's average center of mass height through the concepts of equivalent contact area and volume. The water concentration is varied from 50% to 90% in the alcohol mixture. ContactAngleCalculator code is modified to calculate the contact angle of binary liquids. Results show that increasing alcohol concentration leads to greater spreading. This work has been done in collaboration with Abdulkareem U.

Manzoor A. Malik

Exploring the link between convectively generated gravity waves and ionospheric anomalies: Insights from observations near the low-mid latitude geomagnetic transition region

We examine the role of gravity waves (GWs) generated from tropospheric convection in initiating multiple nighttime ionospheric anomalies over Srinagar, located at 34.1°N, 74.8°E, and 25.91°N MLAT. Optical airglow observations during a geomagnetic quiet night (Ap = 4) of 29–30 June 2021, show the presence of plasma depletion tilted by an angle of 14.9° from the geographic North, quasi-periodic south eastward moving wave (QPSEMW), onset of two electrified MSTIDs and generation of plasma depletion channel between two MSTID phase fronts at 250 km altitude. GWs originating from deep convection in troposphere are detected at 85 and 97 km altitudes in OH and 557 nm filters respectively. The GWs in both the filters are propagating northward with almost similar characteristics. The intrinsic time period and vertical wavelength of GWs is estimated to be 11 min and 53 km respectively. We also present the observational indications of localised upliftment of F-layer ionosphere by 38 km, possibly initiated by polarization electric field generated through secondary GWs. The penetration of secondary GWs, generated by the dissipation of convective GWs, beyond the altitude of 500 km is also seen. FORMOSAT-7/COSMIC-2 RO data and SAMI3 model electron density suggest the occurrence of Sporadic-E (Es) layer at around 100 km altitude, caused

by the negative gradient in eastward wind This work has been done in collaboration with Mohammad Rafeeq Rather, Aashiq Hussain Bhat, and T. K.Ramkumar.

Soma Mandal

Spectro-temporal evolution of 4U 1702-429 using AstroSat-NICER

We present the broadband spectral and timing properties of the atoll source 4U 1702-429 using two observations of *AstroSat* with the second one having simultaneous *NICER* data. For both observations, the spectra can be represented by a Comptonizing medium with a black body seed photon source which can be identified with the surface of the neutron star. A disk emission along with a distant reflection is also required for both spectra. For the first observation, the coronal temperature ($\sim$ 7 keV) is smaller than the second ($\sim$ 13 keV), and the disk is truncated at a larger radius, $\sim$ 150 km, compared to the second, $\sim$ 25 km, for an assumed distance of 7 kpc. A kHz QPO at $\sim$ 800 Hz is detected in the first and is absent in the second observation. Modeling the energy-dependent r.m.s and time lag of the kHz QPO reveals a corona size of $\leq$ 30 km. A similar model can explain the energy dependence of the broadband noise at $\sim$ 10 Hz for the second observation. The results suggest that kHz QPOs are associated with a compact corona surrounding the neutron star and may occur when the disk is truncated at large distances. We emphasize the need for more wide-band observations of the source to confirm these results. This work has been done in collaboration with Suchismito Chattopadhyay, Ranjeev Misra, Akash Garg and Sanjay K.Pandey.

Biman J. Medhi

Characterization of the BSS Populations through Statistical, Photometric, and SED Analysis in the Old Open Cluster: NGC 2243,

We present a statistical, photometric, and spectral energy distribution (SED) analysis of the poorly studied old open cluster: NGC 2243, to characterize its blue straggler star (BSS) populations. We applied ensemble-based unsupervised machine learning methods to estimate the membership probabilities using *Gaia* DR3 astrometry data. NGC 2243 is an open cluster that is 3.67 Gyr old with a metallicity of -0.375 dex, situated at a distance of 3.65 Kpc. By analyzing the position of cluster members on the color-magnitude diagram using the MIST Isochrone, we have identified 12 potential BSSs in NGC 2243. We fitted the radial surface density profile and investigated the dynamical state and mass segregation effect of the cluster. It is found that the BSSs are significantly concentrated within the central region. We used data from *Swift*/UVOT, *Gaia* DR3, Pan-STARRS1 DR2, WISE, and 2MASS to fit the SEDs for 12 identified BSSs using VOSA. We estimated the masses of the BSSs from the Hertzsprung-Russell diagram and found that they ranged from 1.25 to 2.22 $M_{\odot}$. Consequently, we concluded that the BSSs likely gained 0.11 to 1.08 $M_{\odot}$ through the mass transfer/merger channel. We discovered a hot companion associated with 1 BSS candidate, which has a temperature of 19000 K, a luminosity of 0.55 $L_{\odot}$, and a radius of 0.065 $R_{\odot}$. The hot companion is probably a white dwarf, with its mass estimated to be approximately 0.18 - 0.20 $M_{\odot}$ and an age of 186 Myr, suggesting it is a post-mass transfer (Case A or Case B) system. This work has been done in collaboration with A. H. Sheikh.

A Statistical, Photometric, and SED Analysis to Characterize the BSS Populations in Old Open Cluster: Berkeley 39

We present a statistical, photometric, and spectral energy distribution (SED) analysis to characterize the blue straggler stars (BSSs) populations in the Galactic old open cluster: Berkeley 39. Berkeley 39 is a 6.16 Gyr old, open cluster located at a distance of 3.99 Kpc. *Gaia* DR3 astrometry data has been used to estimate the membership probabilities using ensemble-based unsupervised machine learning techniques. We identified 21 BSS candidates on the color-magnitude diagram, with 19 of them being detected in the *Swift*/UVOT UVW2 filter. We analyzed the radial surface density profile and examined the cluster dynamical states and mass segregation effect. The SEDs of 19 BSSs are constructed using multiwavelength data covering UV to IR wavelengths. A single-component SED is fitted successfully for 14 BSS candidates. We discovered hot companions in 5 BSS candidates. These hot companions have temperatures of approximately 14000 to 23000 K, radii ranging from 0.04 to 0.13 $R_{\odot}$, and luminosities ranging from 0.16 to 2.91 $L_{\odot}$. Among these, 3 are most likely extremely low mass (ELM) white dwarfs (WDs) with masses around 0.17 to 0.18 $M_{\odot}$, and 2 are low mass WDs with masses around 0.18 to 0.39 $M_{\odot}$. This confirms that they are post-mass transfer (Case A or Case B) systems. We also investigated the variable characteristics of BSSs by

analyzing their light curves using data from the *TESS*. Our analysis confirms that 2 BSSs identified as eclipsing binaries in *Gaia* DR3 are indeed eclipsing binaries. Additionally, one of the two eclipsing binary BSSs shows evidence of having hot companions, as indicated by the multiwavelength SEDs. This work has been done in collaboration with A. H. Sheikh.

Poonam Mehta

Sterile sector impacting the correlations and degeneracies among mixing parameters at the Deep Underground Neutrino Experiment

We investigate the physics potential of the upcoming Deep Underground Neutrino Experiment (DUNE) in probing active-sterile mixing. We present analytic expressions for relevant oscillation probabilities for three active and one sterile neutrino of eV-scale mass and highlight essential parameters impacting the oscillation signals at DUNE. We then explore the space of sterile parameters as well as study their correlations among themselves and with parameters appearing in the standard framework (δ13 and θ23). We perform a combined fit for the near and far detector at DUNE using GLoBES. We consider alternative beam tune (low energy and medium energy) and runtime combinations for constraining the sterile parameter space. We show that charged current and neutral current interactions over the near and far detector at DUNE allow for an improved sensitivity for a wide range of sterile neutrino mass splittings. This work has been done in collaboration with Sabila Parveen, Mehedi Masud,and Mary Bishai.

Signals of eV-scale sterile neutrino at long baseline neutrino experiments

While most of the results of the neutrino oscillation experiments can be accommodated within the standard paradigm of three active flavor, there are tantalizing hints of an light eV-scale sterile neutrino from anomalous results of a few short baseline experiments. This additional light sterile neutrino is expected to leave an imprint on the physics observables pertaining to standard unknowns such as determination of the Dirac-type leptonic CP phase, δ13, the question of neutrino mass hierarchy and the octant of θ23. The upcoming long baseline neutrino experiments such as T2HK, DUNE and P2O will be sensitive to active - sterile mixing. In the present work, we examine and assess the capability of these long baseline experiments to probe the sterile neutrino at the level of probabilities and event rates. We perform a detailed study by taking into account the values of parameters that are presently allowed and (a) study the impact on CP violation by examining the role played by various appearance and disappearance channels, (b) address the question of disentangling the intrinsic effects from extrinsic effects in the standard paradigm as well as three active plus one light sterile neutrino, and finally (c) assess the ability of these long baseline experiments to distinguish between the two scenarios. Our results indicate that for the true values of sterile parameters and for all values of δ13, the sensitivity of P2O is the lowest while the sensitivity of T2HK is modest ($<3\sigma$) and the sensitivity of DUNE is $>3\sigma$. For larger values of the sterile mixing angles, there is an improvement in the sensitivity for all the three considered experiments.This work has been done in collaboration with Sabila Parveen, Kiran Sharma, and Sudhanwa Patra.

Manesh Michael

Effects of Heavier Ions and on the Characteristics of Ion-Acoustic Double Layers in Comet 1P/Halley

The effects of pair ions (O+ & O-) on the existence and propagation characteristics of ion-acoustic double layers (IADLs) are studied in a six-component cometary plasma, consisting of two hot and one colder components of electrons, hot ions, and a pair of heavier ions. One of the hotter and the colder component of electrons, together with the lighter hydrogen ions, is modeled by kappa distributions. The second, hotter component of electron is modeled by a q -nonextensive distribution. Both the Korteweg–deVries (KdV) and the modified KdV (mKdV) equations are derived for the system and its solutions are studied for parameters pertinent to comet Halley. It is observed that the strength of the DL profile and depth of the Sagdeev potential significantly depend on the heavier ion densities. The variations of both the quadratic and cubic nonlinearities with densities of the heavier ions are also studied. Our results can be expected to contribute to an understanding of DLs in cometary plasmas. This work has been done in collaboration with S. Shilpa, Sijo Sebastian, and Chandu Venugopa.

Hameeda Mir

Revisiting the Schwarzschild black hole solution: A distributional approach

We present a novel perspective on the Schwarzschild, Reissner–Nordstrom, and Massless Black Holes solutions, a cornerstone of general relativity, by employing a distributional approach. The conventional solutions are shown to be incomplete, failing to capture the true nature of the gravitational field near the black hole's singularity. Drawing from advanced concepts in functional analysis and distribution theory, we derive generalized solutions that resolves the apparent singularities and provides new insights into the behaviour of matter and energy in the vicinity of a black hole. Our findings suggest the possibility of quantum tunnelling, allowing particles to traverse the event horizon under specific conditions. This work not only offers a more rigorous treatment of the Schwarzschild, Reissner–Nordstrom and Massless Black Hole solutions but also paves the way for a deeper understanding of black hole physics and the interplay between general relativity and quantum mechanics. This work has been done in collaboration with Qudsia Gani, B. Pourhassan, M.C. Rocca

Statistical mechanics description of an empirical scenario in which gravity was discussed when coupled to a harmonic oscillator

We attempt to construct a (two-dimensional) statistical mechanics description of the scenario in which the experiment in [T. Westphal et al., Nature591, 225 (2021)] was made. It includes two masses that, simultaneously, (1) interact classically via the Newton gravitation and (2) harmonically vibrate. Within the strictures of Gibbs canonical ensemble at the temperature T, our treatment is exact. This work has been done in collaboration with A. Plastinor, and M. C. Rocca.

Bivudutta Mishra

Stability of $f(Q, B)$ Gravity via Dynamical System Approach: A Comprehensive Bayesian Statistical Analysis

In this work, we explore the cosmological stability of $f(Q, B)$ gravity using a dynamical system approach, where Q denotes the nonmetricity scalar and B represents the boundary term. We determine the model parameters of $f(Q, B)$ through Bayesian statistical analysis, employing Markov Chain Monte Carlo techniques. This analysis incorporates numerical solutions and observational data from cosmic chronometers, the extended *Pantheon+* data set, and baryonic acoustic oscillation measurements. Our findings reveal a stable critical point within the dynamical system of the model, corresponding to the de Sitter phase, which is consistent with current observations of the Universe dominated by dark energy and undergoing late-time accelerated expansion. Additionally, we utilize center manifold theory to examine the stability of this critical point, providing deeper insights into the behavior of the model. The cosmological implications of $f(Q, B)$ gravity indicate a smooth transition in the deceleration parameters from deceleration to the acceleration phase, underscoring the potential of the model to describe the evolution of the Universe. Our results suggests that the $f(Q, B)$ model presents a viable alternative to the standard ΛCDM model, effectively capturing the observed acceleration of the Universe and offering a robust framework for explaining the dynamics of cosmic expansion. This work has been done in collaboration with Santosh V. Lohakare.

Scalar field induced dynamical evolution in teleparallel gravity

In this paper, we investigate the role of scalar field potentials in the dynamical evolution of the Universe. A gravity theory with a non-minimally coupled scalar field with torsion in the geometrical action simulating effective dark energy is considered to study an extended matter bounce scenario. The dynamical behaviour of the equation of state parameter has been studied near the bouncing epoch. Keeping in mind the inflationary behaviour near the bounce, five different scalar field potential functions are explored, and their effect on the equation of state parameter is investigated. This work has been done in collaboration with S.A. Kadam,and S.K. tripathy.

Aditya Sow Mondal

Relativistic X-ray reflection from the accreting millisecond X-ray pulsar IGR J17498-2921

The accreting millisecond X-ray pulsar IGR J17498-2921 went into X-ray outburst on April 13-15, 2023, for the first time since its discovery on August 11, 2011. Here, we report on the first follow-up *NuSTAR* observation of the source, performed on

April 23, 2023, around ten days after the peak of the outburst. The *NuSTAR* spectrum of the persistent emission ($3-60$ keV band) is well described by an absorbed blackbody with a temperature of $kT_{bb} = 1.61 \pm 0.04$ keV, most likely arising from the NS surface and a Comptonization component with power-law index $\Gamma = 1.79 \pm 0.02$, arising from a hot corona at $kT_e = 16 \pm 2$ keV. The X-ray spectrum of the source shows robust reflection features which have not been observed before. We use a couple of self-consistent reflection models, `relxill` and `relxillCp`, to fit the reflection features. We find an upper limit to the inner disc radius of 6 R_{ISCO} and 9 R_{ISCO} from `relxill` and `relxillCp` model, respectively. The inclination of the system is estimated to be $\simeq 40°$ from both reflection models. Assuming magnetic truncation of the accretion disc, the upper limit of magnetic field strength at the pole of the NS is found to be $B \lesssim 1.8 \times 10^8$ G. Furthermore, the *NuSTAR* observation revealed two type I X-ray bursts and the burst spectroscopy confirms the thermonuclear nature of the burst. The blackbody temperature reaches nearly 2.2 keV at the peak of the burst. This work has been done in collaboration with Mahasweta Bhattacharya, Mayukh Pahari, B. Raychaudhuri, R. Ghosh, and G. C. Dewangan.

NuSTAR view of the X-ray transients Swift J174805.3-244637 and IGR J17511-3057

We report on the *NuSTAR* observations of the neutron star low-mass X-ray binary Swift J174805.3-244637 (hereafter Swift J17480) and the accreting millisecond X-ray pulsar IGR J17511-3057 performed on March 4, 2023, and April 8, 2015, respectively. We describe the continuum emission of Swift J17480 with a combination of two soft thermal components and an additional hard X-ray emission described by a power-law. We suggest that the spectral properties of Swift J17480 are consistent with a soft spectral state. The source IGR J17511-3057 exhibits a hard spectrum characterized by a Comptonized emission from the corona. The X-ray spectrum of both sources shows evidence of disc reflection. For the first time, we employ the self-consistent reflection models (`relxill` and `relxillNS`) to fit the reflection features in the *NuSTAR* spectrum. From the best-fit spectral model, we find an inner disc radius (R_{in}) is precisely constrained to $(1.99-2.68)$ R_{ISCO} and inclination to $30 \pm 1°$ for Swift J17480. We determine an inner disc radius of $\lesssim 1.3$ R_{ISCO} and inclination of $44 \pm 3°$ for IGR J17511-3057. A low inclination angle of the system is required for both sources. For the source IGR J17511-3057, spinning at 4.1 ms, the value of co-rotation radius (R_{co}) is estimated to be ~ 42 km ($3.6\ R_{ISCO}$), consistent with the position of inner disc radius as $R_{in} \lesssim R_{co}$. We further place an upper limit on the magnetic field strength of the sources, considering the disc is truncated at the magnetospheric radius. This work has been done in collaboration with Mahasweta Bhattacharya, Mayukh Pahari, B. Raychaudhuri, R. Ghosh, and G. C. Dewangan.

Rupak Mukherjee

Nonlinear Coupling of Kinetic Alfvén Waves and Ion Acoustic Waves in the inner Heliosphere

We study the nonlinear coupling of kinetic Alfvén waves with ion acoustic waves applicable to the Earth's radiation belt and near-Sun streamer belt solar wind using dynamical equations in the form of modified Zakharov systems. Numerical simulations show the formation of magnetic field filamentary structures associated with density humps and dips which become turbulent at later times, redistributing the energy to higher wavenumbers. The magnetic power spectra exhibit an inertial range Kolmogorov-like spectral index value of $-5/3$ for $k_\perp \rho_i < 1$, followed by a steeper dissipation range spectra with indices ~ -3 for the radiation belt case and ~ -4 for the near-Sun streamer belt solar wind case, here $k_\perp$ and ρ_i represent the wavevector component perpendicular to the background magnetic field and the ion thermal gyroradius, respectively. Applying quasilinear theory in terms of the Fokker-Planck equation in the region of wavenumber turbulent spectra, we find the particle distribution function flattening in the superthermal tail population which is the signature of particle energization and plasma heating. This work has been done in collaboration with Mani K Chettri, Vivek Shrivastav, and el al.

Mahadevappa Naganathappa

Investigating spectroscopy and optical responses in azo and non-azo polymeric compounds: a theoretical approach

Three polymeric compounds, designated as PA, PB, and PC, were investigated for their nonlinear optical (NLO) characteristics and spectral properties. These compounds, derived from azo and non-azo structures (namely, (E)-butyl 4-((4-bis(2-chloroethyl)

amino) phenyl) diazenyl) benzoate, (2E,6E)-4-(4-butoxyphenyl)-2,6-bis(4-hydroxybenzylid) cyclohexanone, and 2-(2,6-bis(4-hydroxystyryl) -4H-pyran-4-ylidene) malononitrile), were evaluated for their linear polarization (α), first (β) and second (γ) hyperpolarizabilities using the finite field method. Spectroscopic characterizations, such as geometrical parameters, and vibrational and electronic absorption spectra, were conducted. The study employed the dispersion-corrected B3LYP-D3 method with a diffused and polarized 6-311++ G (d, p) basis set, revealing the superior stability of the three polymers compared to other methods. Electronic absorption spectra were computed using time-dependent density functional theory (TD-DFT) at the same level of theory, finding key parameters such as wavelength of electronic transition, oscillator strength, molecular orbital analysis, and electronic properties. The investigation also explored the dependence of NLO properties like α $\pm$, α^2, β_{HRS}, and depolarization ratio on global parameters like ionization potential, electron affinity, electronegativity, chemical hardness, and electrophilicity index. PA shows greater sensitivity to the first hyperpolarizability. The obtained results show a high total first hyperpolarizability (β_{tot}) up to 22,894 a.u. and a low energy gap of 0.4 eV. Interestingly, the magnitudes of β obtained from the B3LYP method surpassed those obtained from other methods. These findings suggest that the studied polymeric compounds, especially PA, have significant potential for application in optoelectronic devices due to their superior NLO properties and stability.This work has been done in collaboration with Sumalya Kaluva, and Balakrishna Kolli.

Theoretical study of aromatic and N-heterocycles: Potential carriers of interstellar aromatic infrared bands

Heterocycle compounds that contain nitrogen play important roles in astrobiology and terrestrial biology as a building block of nucleic acid. Nitrogen inclusion in polycyclic aromatic hydrocarbons (PAHs) is also proposed to account for the emission band at 6.2 Âµm observed in the interstellar medium (ISM). This work comprehensively studies the theoretical microwave, infrared (IR), and ultraviolet (UV)/visible spectra of aromatic and N-heterocycles in the gas phase and water solvent. In this study, one tricyclic tetrahydroquinoline (THQ) and two fused polycyclic quinolines, and their carboxylic acid substitutions in their neutral and ionic states are reported for the first time. All the calculations are performed at the B3LYP/aug-cc-pVTZ level of theory using the Gaussian 16. The rotational constants are obtained at this level of theory, which are further used to calculate the rotational spectra and their transitions. The IR spectra of these molecules are also reported to discuss possible carriers of the aromatic infrared bands (AIBs) observed in the ISM. The electronic absorption spectra of the molecule are also obtained using the time-dependent density functional theory (TD-DFT) at the same level of theory, allowing us to determine the energy gap between the Highest Occupied Molecular Orbitals (HOMO) and Lowest Unoccupied Molecular Orbitals (LUMO) and discuss their stability. We further estimate the transition wavelength, oscillator strength, and symmetry using the AOMix. This study contributes to understanding the physicochemical properties of the building blocks of genetic molecules. This work has been done in collaboration with Venkata Lakshmi Karri,Takashi Onaka.

Hemwati Nandan

Thermodynamics and lensing of charged black hole surrounded by perfect fluid dark matter

We explore the effect of the plasma (uniform and non-uniform) on the deflection angle of relativistic neutral particles and the light of the charged black hole surrounded by fluid dark matter. It also shows how the plasma modifies the deflection angle aspects for a charged black hole within fluid dark matter. The thermodynamic features of a charged black hole in the background of perfect fluid dark matter are discussed. The temperature, mass, entropy, Gibbs free energy, and heat capacity are also analyzed under the effect of the fluid dark matter parameter. Further, we discuss some different aspects of heat capacity to check the transition from a stable phase to an unstable one for the considered black hole. It is found that all the required properties related to thermodynamics are well satisfied for the different values of charge and perfect fluid parameters. This work has been done in collaboration with Uma Papnoi,Farruh Atamurotov, Prasoon Pandey, G.Mustafa, and Ikhtiyor Saidov.

Gravitational lensing around a dual-charged stringy black hole in plasma background

Abstract One of the strongest tools to verify the predictions of general relativity (GR) has been the

gravitational lensing around various compact objects. Using a dual charged stringy black hole produced from dilaton-Maxwell gravity, we investigate the impact of the plasma parameter on gravitational lensing and black hole shadow in this study. Detailed investigations are performed to mark the impact of the homogeneous and non-homogeneous plasma environment on the electric and magnetic charge parameters of stringy black hole. In order to compare the results, we have also considered the vacuum scenario of the dual charged stringy black hole. Our results show that the effect of homogeneous plasma environment is much stronger in comparison to vacuum for the case of electrically charged stringy black hole. However, in the case of magnetically charged stringy black hole, the deflection angle gets decreased in presence of the homogeneous plasma medium. It has been observed that the radius of the shadow increases in a non-homogeneous plasma environment for electrically charged stringy black hole, whereas it decreases for magnetically charged stringy black hole in presence of the same plasma environment. This study aims to investigate how different plasma environments influence these fascinating astrophysical phenomena. This work has been done in collaboration with Shubham Kala,Amare Abebe,and Saswati Roy.

Dibyendu Nandi

Algebraic Quantification of the Contribution of Active Regions to the Sun's Dipole Moment: Applications to Century-Scale Polar Field Estimates and Solar Cycle Forecasting

The solar cycle is generated by a magnetohydrodynamic dynamo mechanism which involves induction and recycling of the toroidal and poloidal components of the Sun's magnetic field. Recent observations indicate that the Babcock-Leighton mechanism – mediated via emergence and evolution of tilted bipolar active regions – is the primary contributor to the Sun's large-scale dipolar field. Surface flux transport models and dynamo models have been employed to simulate this mechanism, which also allows for physics-based solar cycle forecasts. Recently, an alternative analytic method has been proposed to quantify the Babcock-Leighton process. Here, we utilize this algebraic approach to calculate the contribution of active regions to the Sun's dipole moment and test its efficacy using observations spanning a century. Our results demonstrate that the algebraic quantification approach is reasonably successful in estimating dipole moments at solar minima – providing an independent verification of the role of the Babcock-Leighton mechanism in sustaining the solar cycle. We also show how this method may be utilized for solar cycle predictions; we estimate that solar cycle 25 would be a moderately weak cycle, stronger than cycle 24 and perhaps similar to cycle 20. This work has been done in collaboration with Shaonwita Pal.

The Loss of Starlink Satellites in February 2022: How Moderate Geomagnetic Storms Can Adversely Affect Assets in Low-Earth Orbit

On 3 February 2022, SpaceX launched 49 Starlink satellites, 38 of which unexpectedly de-orbited. Although this event was attributed to space weather, definitive causality remained elusive because space weather conditions were not extreme. In this study, we identify solar sources of the interplanetary coronal mass ejections that were responsible for the geomagnetic storms around the time of launch of the Starlink satellites and for the first time, investigate their impact on Earth's magnetosphere using magnetohydrodynamic modeling. The model results demonstrate that the satellites were launched into an already disturbed space environment that persisted over several days. However, on performing comparative satellite orbital decay analyses, we find that space weather alone was not responsible but conspired together with a low-altitude insertion and low satellite mass-to-area ratio to precipitate this unusual loss. Our work bridges space weather causality across the Sun–Earth system – with relevance for space-based human technologies. This work has been done in collaboration with Yoshita Baruah, Souvik Roy, Suvadip Sinha, Erika Palmerio, Sanchita Pal, and Denny M. Oliveira.

Main Pal

Late-time radio brightening and emergence of a radio jet in the changing-look AGN 1ES 1927+654

We present multi-frequency (5–345 GHz) and multi-resolution radio observations of 1ES 1927+654, widely considered one of the most unusual and extreme changing-look active galactic nuclei (CL-AGN). The source was first designated a CL-AGN after an optical outburst in late 2017 and has since displayed considerable changes in X-ray emission, including the destruction and rebuilding of the X-ray corona in 2019–2020. Radio observations prior to 2023 show a faint and compact radio source typical of radio-quiet AGN. Starting in February 2023, 1ES 1927+654 began

exhibiting a radio flare with a steep exponential rise, reaching a peak 60 times previous flux levels, and has maintained this higher level of radio emission for over a year to date. The 5–23 GHz spectrum is broadly similar to gigahertz-peaked radio sources, which are understood to be young radio jets less than ∼1000 years old. Recent high-resolution VLBA observations at 23.5 GHz now show resolved extensions on either side of the core, with a separation of ∼0.15 pc, consistent with a new and mildly relativistic bipolar outflow. A steady increase in the soft X-ray band (0.3–2 keV) concurrent with the radio may be consistent with jet-driven shocked gas, though further observations are needed to test alternate scenarios. This source joins a growing number of CL-AGN and tidal disruption events which show late-time radio activity, years after the initial outburst. This work has been done in collaboration with Eileen T. Meyer, Sibasish Laha, Onic I. Shuvo, Agniva Roychowdhury, David A. Green,and Lauren Rhodes et al.

Very High Energy Gamma-ray episodic activity of radio galaxy NGC 1275 in 2022-2023 measured with MACE

The radio galaxy NGC 1275, located at the central region of Perseus cluster, is a well known very high energy gamma-ray emitter. The Major Atmospheric Cherenkov Experiment (MACE) telescope has detected two distinct episodes of Very High Energy (VHE, E > 80 GeV) gamma-ray emission from NGC 1275 during the period from December 2022 and January 2023. The second outburst, observed on January 10, 2023, was more intense of the two, with flux reaching 58 % of the Crab Nebula flux above 80 GeV. The differential energy spectrum measured between 80 GeV and 1.5 TeV can be described by a power-law with a spectral index of $\Gamma = -2.90 \pm 0.16_{\rm stat}$ for both flaring events. The broadband Spectral Energy Distribution (SED) derived from these flares, along with quasi-simultaneous low-energy counterparts, suggests that the observed gamma-ray emission can be explained using a homogeneous single-zone Synchrotron Self-Compton (SSC) model. The physical parameters derived from this model for both flaring states are similar. The intermediate state observed between two flaring episodes is explained by a lower Doppler factor or magnetic field, which subsequently returned to its previous value during the high activity state observed on January 10, 2023. This work has been done in collaboration with S. Godambe, N. Mankuzhiyil, C. Borwankar, B. Ghosal,and A. Tolamatti et al.

Biswajit Pandey

Tracing the green valley with entropic thresholding

The green valley represents the population of galaxies that are transitioning from the actively star-forming blue cloud to the passively evolving red sequence. Studying the properties of the green valley galaxies is crucial for our understanding of the exact mechanisms and processes that drive this transition. The green valley does not have a universally accepted definition. The boundaries of the green valley are often determined by empirical lines that are subjective and vary across studies. We present an unambiguous definition of the green valley in the colour-stellar mass plane using the entropic thresholding. We first divide the galaxy population into the blue cloud and the red sequence based on a colour threshold that minimizes the intra-class variance and maximizes the inter-class variance. Our method splits the region between the mean colours of the blue cloud and the red sequence into three parts by maximizing the total entropy of that region. We repeat our analysis in a number of independent stellar mass bins to define the boundaries of the green valley in the colour-mass diagram. Our method provides a robust and natural definition of the green valley.

The roles of environment and interactions on the evolution of red and blue galaxies in the EAGLE simulation

We study the evolution of the red and blue galaxies from $z = 3$ to $z = 0$ using the EAGLE simulation. The galaxies in the blue cloud and the red sequence are separated at each redshift using a scheme based on Otsu's method. Our analysis shows that the two populations have small differences in the local density and the clustering strength until $z = 2$, after which the red galaxies preferentially occupy the denser regions and exhibit a significantly stronger clustering than the blue galaxies. The significant disparities in cold gas mass and specific star formation rate (sSFR) observed before $z = 2$ suggest that factors beyond environmental influences may also contribute to the observed dichotomy. Interacting galaxy pairs at a given separation exhibit a higher SFR at increasing redshifts, which may be linked to the rising gas fractions at higher redshift. As redshift decreases, the SFR decreases across all separations, suggesting a gradual depletion of the cold gas reservoir. At pair separations < 50 kpc, an anomalous increase in the SFR among

paired galaxies in isolation around $z \sim 2$ suggests that environmental effects begin to dominate at this redshift, thereby increasing the rate of galaxy interactions and the occurrence of starburst galaxies. We observe a substantial decrease in the blue fraction in paired galaxies starting from $z = 1$ to the present. However, the decrease in the blue fraction in paired galaxies with their second nearest neighbour at a distance greater than 500 kpc continues until $z = 0.5$, after which the blue fraction begins to increase. This work has been done in collaboration with Apashanka Das.

Mahadev Pandge

Exploring the hot gaseous halo around an extremely massive and relativistic jet launching spiral galaxy with XMM-Newton

We present highly resolved and sensitive imaging of the five nearby massive spiral galaxies (with rotation velocities $> 300 \mathrm{kms}^{-1}$) observed by the UltraViolet Imaging Telescope onboard India's multi-wavelength astronomy satellite ASTROSAT, along with other archival observations. These massive spirals show a far-ultraviolet star formation rate in the range of $\sim 1.4-13.7 \mathrm{M}_{\odot}\mathrm{yr}^{-1}$ and fall in the 'Green Valley' region with a specific star formation rate within $\sim 10^{-11.5}-10^{-10.5}\mathrm{yr}^{-1}$. Moreover, the mean star formation rate density of the highly resolved star-forming clumps of these objects are in the range $0.011-0.098 \mathrm{M}_{\odot}\mathrm{yr}^{-1}\mathrm{kpc}^{-2}$, signifying localised star formation. From the spectral energy distributions, under the assumption of a delayed star formation model, we show that the star formation of these objects had peaked in the period of $\sim$ 0.8−2.8 Gyr after the 'Big Bang' and the object that has experienced the peak sooner after the 'Big Bang' show relatively less star-forming activity at $z \sim 0$ and falls below the main-sequence relation for a stellar content of $\gtrsim 10^{11}\mathrm{M}_{\odot}$. We also show that these objects accumulated much of their stellar mass in the early period of evolution with $\sim 31-42$ per cent of the total stellar mass obtained in a time of $(1/16)-(1/5)^{\mathrm{th}}$ the age of the Universe. We estimate that these massive objects convert their halo baryons into stars with efficiencies falling between $\sim 7-31$ percent. This work has been done in collaboration with M. S. Mirakhor, S. A. Walker, J. Bagchi, A. C. Fabian, A. J. Barth, and F. Combes el al.

Cool-core, X-ray cavities and cold front revealed in RXCJ0352.9+1941

This paper presents a comprehensive analysis of 30 ks *Chandra* and 46.8 ks (13 Hr) 1.4 GHz GMRT radio data on the cool-core cluster RXCJ0352.9+1941 with an objective to investigate AGN activities at its core. This study confirms a pair of X-ray cavities at projected distances of about 10.30 kpc and 20.80 kpc, respectively, on the NW and SE of the X-ray peak. GMRT L band (1.4 GHz) data revealed a bright radio source associated with the core of this cluster hosting multiple jet-like emissions. The spatial association of the X-ray cavities with the inner pair of radio jets confirm their origin due to AGN outbursts. The 1.4 GHz radio power $7.4 \pm 0.8 \times 10^{39}\,\mathrm{erg\,s}^{-1}$ is correlated with the mechanical power stored in the X-ray cavities ($\sim 7.90 \times 10^{44}\ \mathrm{erg\ s}^{-1}$), implying that the power injected by radio jets in the ICM is sufficient enough to offset the radiative losses. The X-shaped morphology of diffuse radio emission seems to be comprised of two pairs of orthogonal radio jets, likely formed due to a spin-flip of jets due to the merger of two systems. The X-ray surface brightness analysis of the ICM in its environment revealed two non-uniform, extended spiral-like emission structures on either side of the core, pointing towards the sloshing of gas due to a minor merger and might have resulted in a cold front at ∼31 arcsec (62 kpc) with a temperature jump of 1.44 keV.This work has been done in collaboration with Satish S. Sonkamble, S. K. Kadam,and Surajit Paul.

Amit Pathak

Theoretical Investigation of Interstellar 3-Pyrroline: Formation, Rotational and Vibrational Spectroscopy

The recent detection of CN-functionalized aromatics partly addresses the long-standing mystery of the apparent absence of five- and six-membered rings in interstellar environments. Nitrogen (N)-heterocycles, which are crucial as the fundamental structures of nucleobases, have been a focus of these aromatic searches due to their biological significance. Although N-heterocycles have not been conclusively detected in astrophysical environments, their presence in chondrites and meteorites signifies their interstellar and circumstellar connection. Precise spectral data identify the unique signatures of molecules, confirming their presence in space. In this light, this work reports an extensive computational investigation on interstellar 3-pyrroline, a five-membered ring N-heterocycle. This

includes an alternative formation route in cold interstellar environments and highly accurate rotational and vibrational spectroscopy. The results indicate that 3-pyrroline can form on dust grain surfaces from vinyl cyanide, as its formation from pyrrole through double hydrogenation may lead to the formation of pyrrole itself via an H2-abstraction process. 3-Pyrrolineâ€™s rotational transition at 52.3 GHz offers a potential tool for its detection in cold interstellar regions. Additionally, the strongest infrared (IR) features of 3-pyrroline at 16.09 and 3.50 μm are observable with JWST. The provided data are crucial for laboratory identification and future interstellar observations of 3-pyrroline at both radio and IR wavelengths. This work has been done in collaboration with A. Pandey, A. Vats, S. Srivastav, and K. A. P. Singh.

Theoretical Rotational and Vibrational Investigation of Oxygen-Functionalized Interstellar PAHs

Oxygen-functionalized polycyclic aromatic hydrocarbons (OPAHs) with OH, CHO, and CO side groups can form in the interstellar medium (ISM) mainly through the UV irradiation of PAHs in water ice. Inspired by the detection of nitrogen-containing PAHs in the ISM, this study uses highly accurate computational techniques to investigate the rotational and vibrational spectra of oxygen-functionalized pyrene derivatives ($Py-OH, Py-CHO, Py-HO, and Py-O$) for comparison with experiments that could aid in their future detection. All four OPAHs exhibit strong dipole moments and rotational lines, observable in denser ISM regions near 12 GHz, 10.2 GHz, 12.6 GHz, and 9.6 GHz, respectively. The strongest IR absorption features are identified at 1179.9 cm^{-1} (8.47 μm) and 1385.0 cm^{-1} (7.22 μm) for Py-OH, 1733.4 cm^{-1} (5.77 μm) for Py-CHO, 1747.7 cm^{-1} (5.72 μm) for Py-HO, and 1613.0 cm^{-1} (6.20 μm) for Py-O. The IR features of Py-OH and Py-O exhibit peaks in the CO stretching region around 6.0 μm, while those of Py-CHO and Py-HO are blue-shifted due to anharmonicity from the additional CH bond. This suggests PAHs with CO group and no additional peripheral CH bond better explain the observed 6.0 μm PAH emission. However, to explain the observed PAH emission bands with the OPAHs, a fully emission-cascade treatment is required in the anharmonic IR spectra. The accurate spectral data presented here are crucial for experimental classification and potential interstellar observations. This work has been done in collaboration with S. Mishra, A. Vats, S. Srivastav, P.J. Sarre, T. Onaka, and I. Sakon.

Kishor Dnyandeo Patil

X- X-Ray Emission From Hot GAS And XRB S In The NGC 5846 Galaxy

This paper presents X-ray emission characteristics of the brightest member of G50 group NGC 5846 employing high resolution Chandra X-ray data. This analysis detected 41 discrete sources within the optical D 25 extent of NGC 5846. The crude spectral characteristics of these sources revealed that majority of them fall in the category of LMXBs with a neutron star as the accretor. Among 41 sources, 5 were found to be more luminous with their luminosity exceeding the Eddington limit and were found to occupy positions in the softer region of the X-ray color-color plot exhibiting high-soft state like the ULXs. Main source of the observed X-ray luminosity of NGC 5846 happens to be the diffusely distributed plasma making its contribution up to about 90 % of its total value, while that from the resolved and unresolved point sources at the most up to 10%. The surface brightness distribution of X-ray emitting gas in this galaxy exhibits structures in the form of discontinuities due to the presence of cold fronts. This analysis has witnessed a pair of fronts on the NE (at $\sim$ 20 kpc) and along SW (at $\sim$ 50 kpc). The surface brightness profile, the radial and sectorial temperature profiles revealed the presence of such cold fronts at these locations and may have been formed due to the minor mergers. Floor in the entropy profile at the core point towards reheating of the plasma due to AGN. Observed large values of emission line flux ratio log g([N II]/H) also hint towards a non-thermal ionization source such as low level AGN activity. This work has been done in collaboration with Anil Kyamdampure, N.D.Vagshette.

Equatorial plasma bubble association with lower atmospheric gravity waves – Further evidences

Space based radio wave communication and navigation has become need of the society. Atmospheric (thermospheric-ionospheric) processes, such as Equatorial Plasma Bubbles (EPBs), affect the radio waves propagating through this region, causing heavy perturbations on signals received at ground. This paper investigates the causative mechanism of EPB through the ground based remotely sensed imaging observations of O (1S) 557.7 nm and O (1D) 630.0 nm emissions emanating from the upper mesosphere (100 km altitudes) and thermosphere-ionosphere ($\sim$ 250 km altitudes) over a low-latitude station, Kolhapur (16.8Â° N, 74.2Â° E, and dip lat. 10.6Â°N). Our investigation

revealed that the gravity waves evident in OI557.7 nm images exhibit a close association with the observed EPB structures. These mesospheric gravity waves were found to travel from the South to North with horizontal wavelengths 35 and $\sim$ 56 km on 13-14 April and 26-27 April 2015, respectively. The thermosphere-ionosphere measurements exhibited occurrence of the North-South aligned EPB moving to the east with an inter depletion distance (IDD) equal to $\sim$ 44 km and $\sim$ 64 km. These results provide evidences on association of the gravity waves with the EPB. This work has been done in collaboration with R.N. Ghodpage, A. Taori, O.B. Gurav, R.P. Patil and S. Sripathi.

Madhav Patil

Sloshing and spiral structures breeding a putative radio mini-halo in the environment of a cool-core cluster Abell 795

Spiral structures and cold fronts in X-rays are frequently observed in cool core galaxy clusters. However, studies on radio mini-haloes associated with such spirals and their physical connections are rare. Here, we present the detection of an extended diffuse radio emission entrained in the X-ray spiral structure in a known cool core cluster Abell 795 (A795). Though the cool core is a sign of the relaxed nature of the clusters, our re-analyzed 30 ks Chandra X-ray data of cluster A795 confirms the presence of an interesting log spiral structure of X-ray deficit region complemented by an X-ray excess counter spiral in the residual map, exposing its dynamical activity. Our new analysis of 150 & 325 MHz GMRT archival data of the cluster confirms the detection of a $\sim$ 180 kpc ultra-steep ($\alpha \sim 2.7$) diffuse radio structure which was previously reported as a candidate radio mini halo from low sensitive survey maps. This radio emission spans the entire spiral structure (186 kpc), enclosed by two previously reported cold fronts. Furthermore, SDSS DR13 optical spectra, as well as GALEX's FUV data, show a considerably low total star formation rate of 2.52 $M_{\odot}$ yr^{-1} and having no significant variation in metallicity distribution. We argued that the two-phase (hot and cold) plasma at the cluster core with differential velocity has probably caused the spiral formation and has redistributed the secondary electrons from the central BCG or the pre-accelerated electrons which have been (re-)accelerated by the sloshing turbulence to form the observed candidate radio mini-halo structure. This has been supported by a few previous studies that indicate spiral formation and sloshing turbulence may quench star formation and facilitate smooth metallicity distribution by mixing the gas in the core.

Sloshing Cold Fronts in Galaxy Cluster Abell 2566

This paper presents properties of the intracluster medium (ICM) in the environment of a cool core cluster Abell 2566 (redshift z = 0.08247) based on the analysis of 20 ks Chandra X-ray data. 2D imaging analysis of the Chandra data from this cluster revealed spiral structures in the morphology of X-ray emission from within the central 109 kpc formed due to gas sloshing. This analysis also witness sharp edges in the surface brightness distribution along the south-east and north-west of the X-ray peaks at 41.6 kpc and 77.4 kpc, respectively. Spectral analysis of 0.5 - 7 keV X-ray photons along these discontinuities exhibited sharp temperature jumps from 2.3 to 3.1 keV and 1.8 to 2.8 keV, respectively, with consistency in the pressure profiles, implying their association with cold fronts due to gas sloshing of the gas. Further confirmation for such an association was provided by the deprojected broken power-law density function fit to the surface brightness distribution along these wedge shaped sectorial regions. This study also witness an offset of 4.6 (6.8 kpc) between the BCG and the X-ray peak, and interaction of the BCG with a sub-system in the central region, pointing towards the origin of the spiral structure due to a minor merger.

Bikash C. Paul

X-ray Pulsars Data Analysis: NuSTAR and NICER observations of X Persei

The timing and spectral properties of the persistent Be/ X-ray pulsar namely, X Persei are analyzed using the NuSTAR and NICER observations taken in 2019. The pulsar is in spin-up phase since 2003 with a spin-up rate $\sim (?3.18 \pm 0.04)10^{-4} yr^{-1}$. Using NuSTAR and NICER observations, a broadband (0.7-79) keV energy spectral fitting is performed. It is found that the two component model considered here fits the spectrum more satisfactorily than the single-component model. An additional GABS model was used to fit an absorption-like feature found in the residuals of the spectrum fitted by the two components model. We interpret the absorption-like feature in the spectrum with a cyclotron line as reported in the literature. The centroid energy of the absorption-like feature is found to exist in the energy range of (32.5- 36.0) keV.

The absorption feature is independent of the models used in fitting the spectrum. The broadband spectrum is also fitted making use of the physical bulk and thermal Comptonization model indicating that thermal Comptonization dominates over bulk Comptonization. This work has been done in collaboration with B. Rai, Md. Tobrej, M. Ghising, and R. Tamang.

Cosmology : Observational constraints on the emergent universe with non-linear equation of state and interacting fluids

A flat emergent universe (EU) with a nonlinear equation of state equivalent to three different composition of fluids is investigated. In the EU, the universe evolves out from a static Einstein phase in the infinite past which may be the throat of a dynamical wormhole. In the beginning the evolution of the universe began with no interaction but as time evolves an interaction sets in among the three fluids admitting the observed universe at different phases of evolution. In the EU scenario, we consider a nonlinear equation of state, which yields a universe with three different fluids, it can be identified with dark energy, cosmic string, and radiation domination to begin with for a given equation of state parameter, at a later epoch it transits into a universe with three different fluids with matter domination (baryonic as well as dark matter) can be realized with dark energy for a given interaction strength among the cosmic fluids. The evolution of the universe is probed with exponential interactions to obtain a universe with late acceleration. The model parameters are constrained using the observed Hubble data and Type Ia Supernova (SnIa) data from the Pantheon data set. In the paper we present an interacting EU which transits to a matter dominated phase with DE accommodating the present universe satisfactorily. The stability of the cosmological model is also explored. This work has been done in collaboration with A. Chanda, B. C. Roy, and Kazuharu Bamba

Devraj Pawar

X-ray Study on core collapse supernova 2008ax using XMM-Newton and Swift/XRT

XB 1254-690 is a neutron star low-mass X-ray binary with an orbital period of 3.88 h, and it exhibits energy-dependent intensity dips, thermonuclear bursts, and flares. We present the results of an analysis of a long observation of this source using the AstroSat satellite. The X-ray light curve gradually changed from a high-intensity flaring state to a low-intensity one with a few dips. The hardnessintensity diagram showed that the source is in a high-intensity banana state with a gradually changing flux. Based on this, we divide the observation into four flux levels for a flux-resolved spectral study. The X-ray spectra can be explained by a model consisting of absorption, thermal emission from the disc, and non-thermal emission from the corona. From our studies, we detect a correlation between the temperature of the thermal component and the flux and we examine the implications of our results for the accretion disc geometry of this source. This work has been done in collaboration with Ahmed Fouad, SH. M. Shehata et al.

X-ray study on the core collapse supernova 2008ax using XMM-Newton and Swift/XRT

We studied the X-ray evolution of the core collapse, Type IIb, supernova SN 2008ax. In addition to the four Swift/XRT observations previously published, we included, for the first time, two observations from XMM-NEWTON to our analysis that have not been published before. By focusing on the early observations of the SN 2008ax, we were able to explore the time evolution of both X-ray luminosity (L_x) and temperature (T_x) during the radiative phase. The analysis showed that the evolution of L_x and T_x can be expressed as a power law as $L_x \propto t^{-0.87}$ and $T_x \propto t^{-0.46}$, respectively. Based on the observed X-ray luminosity, we estimated the mass loss rate ($\dot{M}$) for the progenitor star to be approximately $0.64 \pm 0.15 \times 10^{-5} M_{\odot} yr{-}1$, for a wind velocity of 10 km s$^{\hat{}\prime 1}$. This finding is in good agreement with previous studies. This work has been done in collaboration with Ahmed M Fouad, SH M Shehata et al.

Ananta Charan Pradhan

A Comprehensive Catalog of UVIT Observations. I. Catalog Description and First Release of Source Catalog (UVIT DR1

We present the first comprehensive source catalog (UVIT DR1) of ultraviolet (UV) photometry in four far-UV (FUV: 1300-1800 Å) and five near-UV (NUV : 2000-3000 Å) filters of the Ultraviolet Imaging Telescope (UVIT) on board AstroSat. UVIT DR1 includes bright UV sources in 291 fields that UVIT detected during its first 2 yr of pointed observation, encompassing an area of 58 deg^2. We used the ccdlab pipeline to reduce the Level 1 data, SExtractor for source detection, and four

photometric procedures to determine the magnitudes of the detected sources. We provided the 3Ïf and 5Ïf detection limits for all the filters of UVIT. We describe the details of observation, source extraction methods, and photometry procedures applied to prepare the catalog. In the final UVIT DR1 catalog, we have point sources, extended sources, clumps from nearby galaxies, globular clusters, open clusters, planetary nebulae, and gaseous nebulae. There are 239,520 unique sources in the combined UVIT DR1, of which 70,488 sources have FUV magnitudes, and 211,410 have NUV magnitudes. We crossmatched and compared noncrowded sources of UVIT with the Galaxy Evolution Explorer and Gaia source catalogs. We provide a clean catalog of the unique sources in various UVIT filters that will help further the multiwavelength scientific analysis of the objects. This work has been done in collaboration with Sonika Piridi, Ranjan Kumar,and Divya Pandey.

Discovery of a hot post-AGB star in Galactic globular cluster E3

We report a new hot post-asymptotic giant branch (PAGB) star in the Galactic globular cluster (GC) E3, which is one of the first of the identified PAGB stars in a GC to show a binary signature. The star stands out as the brightest source in E3 in the Astrosat UVIT images. We confirmed its membership with the cluster E3 using Gaia DR3 kinematics and parallax measurements. We supplemented the photometric observations with radial velocities (RVs) from high-resolution spectroscopic observations at two epochs and with ground- and space-based photometric observations from 0.13 μm to 22 μm. We find that the RVs vary over $\sim$6 km/s between the two epochs. This is an indication of the star being in a binary orbit. A simulation of possible binary systems with the observed RVs suggests a binary period of either 39.12 days or 17.83 days with mass ratio q$\geq$1.0. The [Fe/H] derived using the high-resolution spectra is $\sim$ $-$0.7 dex, which closely matches the cluster metallicity. The spectroscopic and photometric measurements suggest T_{eff} and $log\, g$ of the star as 17 500$\pm$1 000 K and 2.37$\pm$0.20 dex, respectively. Various PAGB evolutionary tracks on the Hertzsprung–Russell (H-R) diagram suggest a current mass of the star in the range 0.51$-$0.55 solar mass. The star is enriched with C and O abundances, showing similar CNO abundances compared to the other PAGB stars in GCs with the evidence of the third dredge-up on the AGB phase. This work has been done in collaboration with R. Kumar, A. Moharana, S. Piridi, and K.G. Hełminiak et al.

Anirudh Pradhan

Investigating stable quark stars in Rastall-Rainbow gravity and their compatibility with gravitational wave observations

We present a stable model for quark stars in Rastall-Rainbow (R-R) gravity. The structure of this configuration is obtained by utilizing an interacting quark matter equation of state. The R-R gravity theory is developed as a combination of two distinct theories, namely, the Rastall theory and the gravity's rainbow formalism. Depending on the model parameters $(\bar{\lambda}, \eta, \Sigma, B_{eff})$, the mass-radius relations are numerically computed for modified Tolman-Oppenheimer-Volkoff (TOV) equations with proper boundary conditions. The stability of equilibrium configuration has been checked through the static stability criterion, adiabatic index and the sound velocity. Our calculations predict larger maximum masses for quark stars, and the obtained results are compatible with accepted masses and radii values, including constraints from GW190814 and GW170817 events in all the studied cases. This work has been done in collaboration with Takol Tangphati, Dhruba Jyoti Gogoi, , and Ayan Banerjee.

Cosmological Implications of $f(R, \Sigma, T)$ Gravity: A Unified Approach Using OHD and SN Ia Data

This paper investigates the cosmological implications of the modfied gravity framework known as $f(R, \Sigma, T)$ gravity, focusing on its potential to unify and extend current cosmological models. The theory, introduced by Bakry and Ibraheem in 2023, combines the Ricci scalar, a scalar parameter representing torsion or other geometric properties, and the trace of the energy-momentum tensor. By analyzing observational Hubble data (OHD) and the Pantheon compilation of Type Ia Supernovae (SN Ia), we explore how this framework provides the accelerated expansion of the universe, the nature of dark energy, and phenomena like the Big Rip singularity. Employing the Friedmann-Robertson-Walker (FRW) metric and solving the modfied field equations, we derive key cosmological parameters such as the Hubble constant and matter energy density parameter. These parameters are constrained through statistical analysis of observational data, yielding and from OHD, and from SN Ia. The evolution of the equation of state (EoS) parameter, isotropic pressure, and energy density

is also investigated. By considering energy conditions and stability criteria, the study highlights the viability of gravity as an alternative framework to General Relativity and models. Our findings affirm the model's compatibility with current observational evidence and its potential to the universe's past and future dynamics. This work has been done in collaboration with N. Myrzakulov,and S. H. Shekh.

Ram Prasad Prajapati

Firehose instability in heat-conducting solar wind plasmas including FLR corrections and electrical resistivity

The effects of finite Larmor radius (FLR) corrections and heat-flux vector are studied on the pressure anisotropy-driven firehose instability in finitely conducting solar wind plasmas described by the double-adiabatic Chew, Goldberger and Low (CGL) fluid theory. The fluid description of collisionless plasmas is governed through modified adiabatic equations due to the heat-flux vector and finite ion Larmor radius corrections. The analytical dispersion relation of the firehose instability has been derived using the normal mode analysis and discussed in the solar wind plasmas. In the transverse mode, the dispersion relation of the Alfvénic mode is modified due to electrical resistivity and FLR corrections. In the longitudinal mode, the effects of the heat-flux parameter and electrical resistivity are observed separately. The dispersion relation of the firehose mode is modified due to the combined effects of FLR corrections and electrical resistivity. The graphical illustrations show that finite electrical resistivity and ion Larmor frequency destabilize the growth rate of the firehose instability. The results are useful for analyzing the solar mission data to study the firehose instability in the solar wind plasmas.

Radiation pressure-driven Rayleigh–Taylor instability in compressible strongly magnetized ultra-relativistic degenerate plasmas

The radiation pressure and strong magnetic fields are prominent in the structures of Rayleigh–Taylor (R–T) instability in the interior of white dwarfs. This paper investigates the radiation pressure-driven R–T instability in a compressible and magnetized ultra-relativistic degenerate strongly coupled plasma. The equation of state has been derived for such systems incorporating ultra-relativistic degenerate electrons with their radiation pressure and ion gas compressibility. The dispersion relation of the density gradients driven R–T instability is analyzed using the generalized hydrodynamic fluid model in the strongly coupled and weakly coupled limits. It is observed that the R–T instability criterion has been modified significantly due to radiation pressure, ion gas compressibility and degeneracy parameters. In the kinetic limit, the instability region is shorter than the hydrodynamic limit due to the dominance of plasma frequency over the viscoelastic relaxation frequency. The outcomes are explored in analyzing the development of R–T instability in the strongly magnetized carbon–oxygen white dwarfs. The radiation pressure, electron temperature and ion density strongly suppress the growth rate of the R–T instability in the interior of white dwarfs. The strong magnetic fields introduce asymmetry to the system by destabilizing the R–T unstable modes. The present results are also useful for understanding the R–T instability in the star formation and dense plasmas in inertial confinement fusion in some limiting cases. This work has been done in collaboration with Ravinder Bhambhu.

Farook Rahaman

Deflection of massive body around wormholes in Einstein–Kalb–Ramond spacetime

The presence of dark matter in the galactic region has decisively confirmed by astronomical observations , however, the characteristics of dark matter yet to be recognized correctly. Utilizing the Einstein's general theory of relativity and the observed rotational curve profile as input, we point out some features of galactic dark matter. Usually, dark matter is not directly visible but affects the lensing. In this paper, the deflection of a massive particle by galactic dark matter is studied using the Jacobi metric approach. We also provide a brief analysis of the image features of the deflection angle. This work has been done in collaboration with A Islam.

Euclidean quantum wormholes

We study wormhole as the solution of the Wheeler–DeWitt(WdW)equation satisfying Hawking–Page wormhole boundary conditions in Friedmann–RobertsonWalker (FRW) cosmology. The quantum wormholes are formulated with arbitrary factor ordering of the Hamiltonian constraint operators with perfect fluid matter sources as well as minimally

coupled scalar fields. This work has been done in collaboration with B S Choudhuri , and A Islam.

Rajesh S.R

A model on transition between steady state of sub-Keplerian accretion discs: Implication for spectral states and hot corona above the disc

We present here a simple hydrodynamic model based on a sequence of steady states of the inner sub-Keplerian accretion disc to understand its different spectral states. Correlations between different hydrodynamic steady states are studied with a goal to understand the origin of, e.g., the aperiodic variabilities. The plausible source of corona/outflow close to the central compact object is shown to be a consequence of steady state transition in the underlying accretion flow. We envisage that this phenomenological model can give insight on the influence of viscosity, efficiency of energy advection, nature of the background flow and environment on the evolution of the inner sub-Keplerian accretion disc. This work has been done in collaboration with Arunima Ajay,and Nishant K Singh.

Reversals of Toroidal Magnetic Field in Local Shearing Box Simulations of accretion Disc with a Hot Corona

Presence of a hot corona above the accretion disc can have important consequences for the evolution of magnetic fields and the Shakura-Sunyaev (SS) viscosity parameter α in such a strongly coupled system. In this work, we have performed three-dimensional magnetohydrodynamical (3D-MHD) shearing-box numerical simulations of accretion disc with a hot corona above the cool disc. Such a two-layer, piece-wise isothermal system is vertically stratified under linear gravity and initial conditions here include a strong azimuthal magnetic field with a ratio between the thermal and magnetic pressures being of order unity in the disc region. Instabilities in this magnetized system lead to the generation of turbulence, which, in turn, governs the further evolution of magnetic fields in a self-sustaining manner. Remarkably, the mean toroidal magnetic field undergoes a complete reversal in time by changing its sign, and it is predominantly confined within the disc. This is a rather unique class of evolution of the magnetic field which has not been reported earlier. Solutions of mean magnetic fields here are thus qualitatively different from the vertically migrating dynamo waves that are commonly seen in previous works which model a single layer of an isothermal gas. Effective α is found to have values between 0.01 and 0.03. We have also made a comparison between models with Smagorinsky and explicit schemes for the kinematic viscosity (ν). In some cases with an explicit ν we find a burst-like temporal behavior in α. This work has been done in collaboration with Nishant K Singh, and Arunima Ajay.

Chayan Ranjit

Cosmological effects on $f(\tilde{R},\tilde{T})$ gravity through a nonstandard theory

This study aims to investigate the impact of dark energy in cosmological scenarios by exploiting $f(\bar{R},\bar{T})$ gravity within the framework of a nonstandard theory, called K-essence theory, where $\bar{R}$ represents the Ricci scalar and $\bar{T}$ denotes the trace of the energy-momentum tensor associated with the K-essence geometry. The Dirac-Born-Infeld (DBI) nonstandard Lagrangian has been employed to generate the emergent gravity metric $\bar{G}\mu\nu$ associated with the K-essence. This metric is distinct from the usual gravitational metric ($g\mu\nu$). It has been shown that under a flat Friedmann-Lemaître-Robertson-Walker (FLRW) background gravitational metric, the modified field equations and the Friedmann equations of the $f(\bar{R},\bar{T})$ gravity are distinct from the usual ones. In order to get the equation of state (EoS) parameter ω, we have solved the Friedmann equations by taking into account the function $f(\bar{R},\bar{T}) \equiv f(\bar{R}) + \lambda\bar{T}$, where λ represents a parameter within the model. We have found a relationship between ω and time for different kinds of $f(\bar{R})$ by treating the kinetic energy of the K-essence scalar field (ϕ^2) as the dark energy density which fluctuates with time. Surprisingly, this result meets the condition of the restriction on (ϕ^2). By presenting graphical representations of the EoS parameter with time, we show that our model is consistent with the data of $SNIa + BAO + H(z)$ within a certain temporal interval. This work has been done in collaboration with Arijit Panda, Saibal Ray, Goutam Manna, and Surajit Das.

Cosmology of the interacting Tsallis holographic dark energy in $f(R,T)$ gravity framework

In this work, we have analyzed the cosmology of the Tsallis holographic dark energy (THDE), a particular case of Nojiri-Odintsov HDE proposed in *Gen. Rel. Grav.* **38** (2006), 1285-1304, *Eur. Phys. J. C* **77** (2017) no.8, 528, using Hubble's horizon cutoff in

$f(R,T) = \mu R + \nu T$ model considering pressureless dark matter. We have examined the equation of state (EoS) parameters in this scenario. The deceleration parameter has been evaluated for this interacting model to justify the late-time acceleration of the expanding universe. We have also studied the cosmological consequences of Statefinder pair, $O_m(z)$ diagnostics, $r-q$ plane, and $w_{DE} - w_{DE}^{'}$ pair for interacting THDE in $f(R,T) = \mu R + \nu T$ model. We have also illustrated the cosmology of the interacting THDE using Hubble's horizon cutoff in $f(R,T) = R + \gamma R^2 + \xi T$ model. The EoS parameter, deceleration parameter and Statefinder pair are studied in this interacting scenario. Attainment of ΛCDM fixed point has been observed for both models. We have also constrained model parameters based on observational data sets through the formalism of χ^2 minimum test.This work has been done in collaboration with Sanjeeda Sultana, Surajit Chattopadhyay, and Ertan Gudekli

C.D. Ravikumar

Deciphering the multi-wavelength flares of the most distant very high-energy (>100 GeV) γ-ray emitting blazar

This study analyzes the multi-wavelength flaring activity of the distant flat spectrum radio quasar (FSRQ) OP 313 (z=0.997) during November 2023 to March 2024, using data from Fermi-Large Area Telescope, Swift X-ray Telescope, and Ultraviolet and Optical Telescope. The analysis highlights two significant very high energy (VHE) detection epochs and GeV gamma-ray flaring episodes, providing insight into jet emission processes and radiative mechanisms. We study the evolution of broadband spectral energy distribution (SED) and identify, for the first time, that the source displays three different characteristics in its synchrotron peaks within a short span of four months, which is rather uncommon in FSRQs. Modeling of the multi-wavelength SED with a one-zone leptonic radiative processes attributes the emissions to synchrotron radiation, Synchrotron Self-Compton (SSC), and External Compton (EC) mechanisms, with torus photons as the primary source for EC processes. The results suggest that the gamma-ray emitting region lies outside the broad-line region but within the dusty torus. Furthermore, we find that the radiated power is significantly smaller than the total jet power, suggesting that most of the bulk energy remains within the jet even after passing through the blazar emission zone. This work was done in collaboration with Naseef Mohammed, P. N., Aminabi, T., Baheeja, C., Sahayanathan, S., and Paliya, Vaidehi S.

Long term multi-wavelength spectral variations of blazar S5 0716+714

We present a comprehensive analysis of simultaneous, long-term observations of blazar S5 0716+714, covering optical/UV, X-ray, and $\hat{\mathbf{I}}^{\mathbf{3}}$ -ray wavelengths. All available observations of the source by Swift-UVOT/XRT and Fermi-LAT till January 2023 were used, and the spectra were fitted using power-law/log-parabola functions. A detailed correlation study between the best-fit parameters were performed, and our results suggest that the spectral changes observed during high flux states could be associated with the spectral energy distribution shifting towards the blue end. The flux distribution predominantly shows a log-normal/double log-normal behaviour, whereas the index distribution indicates a Gaussian or double Gaussian nature. As a Gaussian variation in the index of a power-law spectrum will result in a log-normal variation in the flux, the observed log-normal variability in blazars may be associated with Gaussian variation in the spectral indices. The observed normal/log-normal variations in indices/fluxes can again be interpreted through bluer when brighter behaviour of the source. Furthermore, the broadband SED during two distinct flux states can be successfully fitted by considering synchrotron, synchrotron self-Compton, and external Compton emission processes. The flux enhancement of the source is predominantly associated with an increase in the bulk Lorentz factor. Additionally, we find that the model curves corresponding to variations in the Lorentz factor have the potential to explain the observed correlations between the spectral parameters. Our study thereby concludes that the spectral variations of blazar S5 0716+714 are primarily associated with changes in the bulk Lorentz factor of the jet. This work was done in collaboration with Baheeja, C., Thekkoth, Aminabi., Sahayanathan, Sunder., and Bhatt, Nilay.

Saibal Ray

Modeling compact object mergers GW190814 and GW200210 and other self-bound compact stars with dark matter induced by gravitational decoupling and its significance to mass-gap

Ray and his collaborators have presented a rigorous study on compact objects within $f(Q)$ gravity where electrical fields and dark matter are studied and provide novel mass-radius relations with models falling in the mass gap of the events GW190814 and GW200210. After formulating the basic equations and finding their relevant solutions we impose the boundary conditions on the system under treatment. The decoupled solution for the strange stellar model with dark matter density profile is obtained. The distribution patterns of the effective energy density, the radial as well as the tangential pressure and anisotropy in the system are intensively examined. The stability properties of the stellar configuration and the influence of dark matter are studied. The recent observations of supermassive compact star candidates such as PSR J1614-2230 and PSR J0952-0607 with observed masses greater than or equal to $2M_{\odot}$ have been employed in our study. Interestingly, the present study predicts the constraints on mass-radius measurements of the observed stars satisfying the equation of state based on the MIT bag model and employing the condition of mimicking, i.e., $\rho^{\theta} = \rho_{PI}$ in $f(Q)$ gravity. Our graphical results exhibit that for a particular $M-R$ curve with fixed values of the parameters, neutron stars having mass less than M_{max} exist with larger radii within the context of the $f(Q)$ formalism. This work has been done in collaboration with S. K. Maurya, Abdelghani Errehymy, Ksh. Newton Singh, Abdul Aziz,and Sudan Hansraj,

Dual effect of string cloud and dark matter halos on particle motions, shadows, and epicyclic oscillations around Schwarzschild black holes

Inspired by the conundrum of the gravitational event, GW190814 which brings to light the coalescence of a 23 $M_{\odot}$ black hole with a yet to be determined secondary component, we look to modelling compact objects within the framework of $f(\mathcal{Q})$ gravity by employing the method of gravitational decoupling. We impose a quadratic equation of state (EOS) for the interior matter distribution which in the appropriate limit reduces to the MIT bag model. The governing field equations arising from gravitational decoupling bifurcates into the $\rho = \theta_0^0$ and $p_r = \theta_1^1$ sectors leading to two distinct classes of solutions. Both families of solutions are subjected to rigorous tests qualifying them to describe a plethora of compact objects including neutron stars, strange stars and the possible progenitor of the secondary component of GW190814. Using observational data of mass-radius relations for compact objects LMC X-4, Cen X-3, PSR J1614-2230 and PSR J0740+6620 we show that it is possible to generate stellar masses and radii beyond 2.0 $M_{\odot}$ for neutron stars. Our findings reveal that the most suitable and versatile model in this framework is the quadratic EOS, which accounts for a range of low mass stars as well as typical stellar candidates describing the secondary component of GW190814. This work has been done in collaboration with R.-Y. Chen, F. Javed, S.K. Maurya and G. Mustafa.

Pramit Rej

Polytropic stellar structure in 5D Einstein-Gauss-Bonnet gravity

Polytropic stars are useful tools for learning about stellar structure without the complexity of comprehensive stellar models. These models rely on a certain power-law correlation between the star's pressure and density. This paper proposes a polytropic star model to investigate some new features in the context of $5\mathcal{D}$ Einstein-Gauss-Bonnet (EGB) gravity using the Finch-Skea *ansatz* [*M. R. Finch and J. E. Skea, Classical and Quantum Gravity 6, 467 (1989)*]. Analytical results are better described by graphical representations of the physical parameters for various values of the Gauss-Bonnet coupling constant α. The solution for a specific compact object, EXO 1785-248, with radius $\mathfrak{R} = 8.849^{+0.04}_{-0.04}$ km and mass $\mathcal{M} = 1.3 \pm 0.02\ \mathcal{M}_{\odot}$, is shown here. We analyze the essential physical attributes of the star, which reveal the influence of the coupling parameter α on the values of the parameters. Ultimately, we conclude that our current model is realistic because it satisfies all the physical criteria for an acceptable model. This work has been done in collaboration with Akashdip Karmakar, Ujjal Debnath.

Well behaved class of Heintzmann's solution within $f(R, T)$ framework

The primary objective of this paper is to develop a well-behaved class of Heintzmann IIa [*H. Heintzmann, Z. Physik 228, 489-493 (1969)*] solution in the context of $f(R, T)$ gravity. In the $f(R,T)$ framework, the gravitational action includes both the Ricci scalar (R)

and the trace of the energy-momentum tensor (T). We chose a particular $f(R, T)$ model s.t. $f(R, T) = R + 2\chi T$, where χ is known as the coupling parameter. This solution describes a novel isotropic compact fluid sphere with positively finite central pressure and density in this extended theory of gravity. The results obtained analytically are better described by graphical representations of the physical parameters for various values of the coupling parameter χ. The solution for a specific compact object, Vela X-1, with radius $\Re = 9.56^{+0.08}_{-0.08}$ km and mass $\mathcal{M} = 1.77 \pm 0.08\ \mathcal{M}_{\odot}$ [*M. L. Rawls et al. ApJ, 730, 25 (2011)*], is shown here. We analyze the fundamental physical attributes of the star, which reveals the influence of the coupling parameter χ on the values of substance parameters. This helps us to make a fruitful comparison of this modified $f(R, T)$ gravity with the standard GR and notice that it holds good for stable compact objects. In this framework, the star under our consideration exhibits a stable structure consistent with the Heintzmann IIa *ansatz*. From all of our obtained graphical and numerical results, we can ultimately conclude that our reported model is physically admissible and satisfies all the physical criteria for an acceptable model. This work has been done in collaboration with Akashdip Karmakar.

Prabir Rudra

Gravitational Collapse of Bose-Einstein condensate dark matter in Generalized Vaidya spacetime

In this work we study the gravitational collapse procedure in generalized Vaidya spacetime with Bose-Einstein condensate dark matter density profile. We use the generalized Vaidya metric to simulate the spacetime of a big star and subsequently obtain the field equations. Then we proceed to determine the star system's mass parameter by solving the field equations. Then the gravitational collapse mechanism is investigated using the derived solutions. Investigating the nature of the singularity (if formed) as the end state of the collapse is the main goal. Dark matter in the form of Bose-Einstein condensate is expected to play a crucial role in the fate of the collapse. We see that there is a possibility of the formation of both black holes and naked singularities as the end state of the collapse depending upon the initial conditions. The junction conditions are derived with a Vaidya exterior and a Friedmann interior and some important insights are obtained. A Penrose diagram showing the causal relations between the spacetimes is generated and studied in detail.

Geodesics and thermodynamics of Einstein-Power-Yang-Mills AdS black holes

In this paper, we investigate the geodesic equations in the spacetime of Einstein-Powerâ€“Yangâ€“Mills anti-de Sitter (AdS) black holes. We obtain analytical solutions to the geodesic equations using Weierstrass elliptic and Kleinian sigma hyperelliptic functions. We classify possible orbits such as flyby, bound, terminating bound, and terminating escape orbits based on the analytical solutions and effective potential. We also briefly study the thermodynamics of these black holes, plotting the horizon radius versus mass to demonstrate the possibility of having one or three horizons. We derive expressions for temperature, entropy, pressure, and volume, and interpret the results. We find that there is a possibility of van der Waals-like behavior for the holographic dual fluid corresponding to these Einstein-Power-Yang-Mills AdS black holes. This work has been done in collaboration with Saheb Soroushfar, Ali Iloon Kashkooli, Hoda Farahani, and Behnam Pourhassan.

Sunil Kumar S.

Suppression of collision-induced dissociation in a supersonically expanding gas

In high-resolution mass spectrometry, an electrospray ionizationsource is often paired with an ion-funnel to enhance ion transmission. Although itis established that ions experience collision-induced dissociation as they passthrough this device, the impact of gas-flow dynamics on ion fragmentationremains unexplored. The present work demonstrates that the gas-flow dynamicsfrom the capillary interface of an electrospray ionization source into an ion-funnelsignificantly reduces ion fragmentation. This reduction stems from the substantialdecrease in the rate of increase in the internal energy of the ions, resulting fromthe collisions with a supersonically expanding gas. The results of this study havesignificant consequences for systems that employ electrospray mass spectrometryand ion-mobility spectrometry as well as in interdisciplinary fields involving iontransport through a gaseous medium. This work has been done in collaboration with Uma Namangalam, Salvi Mohandas, and Hemanth Dinesan.

Characterization of a radiofrequency storage ion source using numerical simulations

A radiofrequency ion source routinely employed for laboratory astrophysics and astrochemistry experiments designated as the storage ion source was characterized using numerical simulations. The present work focuses on optimizing the storage and extraction of ions of astrophysical relevance having the m/z range 3−330, which covers most of the molecular ions detected in the interstellar medium and circumstellar envelopes. The crucial parameters for the storage of ions: radiofrequency signal frequency, f_{RF} and amplitude, V_{RF} were optimized, and the range of radiofrequency parameters that can be used to store ions inside the source is presented. The lifetimes of ions inside the source were estimated for various radiofrequency parameters. The difference in the lifetimes of ions of different m/z was explained based on the ionsâ€™ thermalization characteristics and the sources effective potential. The extraction of ions from the source was optimized, and a new design called the T-source was proposed to improve the extraction efficiency. We show that the T-source has better extraction efficiency than the original design, which is further enhanced by maintaining the source at a floating potential. Finally, we investigated the transmission characteristics of the extracted ions through a quadrupole ion guide, which may serve as an ion guide or a mass filter, leading to an ion storage device such as an ion trap or an ion storage ring. This work has been done in collaboration with Nanditha Sunil Kumar, and Vignesh N.

Sanjay K. Sahay

Efficient and Secure Sub-Key Generation for AES Using SHA-3

Advanced Encryption Standard (AES) is one of the most widely used symmetric cipher for the confidentiality of data. Also it is used for other security services, viz. integrity, authentication and key establishment. However, recently, authors have shown some weakness in the generation of sub-keys in AES, e.g. bit leakage attack, etc. Also, AES sub-keys are generated sequentially, which is an overhead, especially for resource-constrained devices. Therefore, we propose and investigate a novel encryption AESHA3, which uses sub-keys generated by Secure Hash Algorithm-3 (SHA3). The output of SHA3 is one-way and highly non-linear, and random. The experimental analysis shows that the average time taken for generating the sub-keys to be used for encrypting the data using our approach i.e. AESHA3 is 1300 times faster than the sub-key generated by the standard AES. Accordingly, we find that AESHA3 will be very relevant not only in terms of security but also it will save the resources in IoT devices. We investigated AESHA3 in Intel Core i7, 6th Generation processor and Raspberry Pi 4B and found that up to two MB data encryption is very significant, and lesser the data size, more the resource saving compared to AES. This work has been done in collaboration with Ankush Soni, and Parit Mehta.

SEASHA3: Secure and Efficient Encryption for the IoT Data by Replacing Subkeys of AES with SHA3

Advanced Encryption Standard (AES) is one of the most widely used cipher for data encryption. However, recent studies have pointed out some weaknesses in the subkeys used in AES. Also, the sequential subkeys generation process of AES seems to be inefficient for resource-constrained IoT devices. Therefore, in this paper, we studied how secure and efficient the Secure Hash Algorithm-3 (SHA3) generated subkeys will be for the encryption of IoT data by just replacing the AES subkeys with it. For this purpose we used the statistical test suite provided by the National Institute of Standards and Technology and found that SHA-3 generated subkeys are highly random, and also it is significantly efficient for encrypting the IoT Data. However, as symmetric keys are repeatedly used, therefore, only upto 2 MB data, the encryption is significantly efficient. From the experimental analysis, we find that SEASHA3 generates subkeys that are random, non-linear, and irreversible, making it more secure and efficient than traditional AES subkey generation. This work has been done in collaboration with Ankush Soni.

Pradyumn Kumar Sahoo

Gaussian Process Approach for Model-Independent Reconstruction of $f(Q)$ Gravity with Direct Hubble Measurements

The increase of discrepancy in the standard procedure to choose the arbitrary functional form of the Lagrangian $f(Q)$ motivates us to solve this issue in modified theories of gravity. In this regard, we investigate the Gaussian process (GP), which allows us to eliminate this issue in a $f(Q)$ model-independent way. In particular, we use the 57 Hubble measurements coming from cosmic chronometers and the radial Baryon acoustic oscillations

(BAO) to reconstruct $H(z)$ and its derivatives $H'(z)$, $H''(z)$, which resulting lead us to reconstruct region of $f(Q)$, without any assumptions. The obtained mean curve along ΛCDM constant in the reconstructed region follows a quadratic behavior. This motivates us to propose a new $f(Q)$ parametrization, i.e., $f(Q) = -2\Lambda + \epsilon Q^2$, with the single parameter ϵ, which signifies the deviations from ΛCDM cosmology. Further, we probe the widely studied power-law and exponential $f(Q)$ models against the reconstructed region and can improve the parameter spaces significantly compared with observational analysis. In addition, the direct Hubble measurements, along with the reconstructed $f(Q)$ function, allow the H_0 tension to be alleviated. This work has been done in collaboration with Gaurav N. Gadbail ,and Sanjay Mandal.

Impact of teleparallalism on addressing current tensions and exploring the GW cosmology

The H_0 and S_8 tensions highlight critical discrepancies in modern cosmology, challenging the standard ΛCDM model. The H_0 tension arises from conflicting measurements between local probes and early-Universe predictions. Similarly, the S_8 tension, related to the amplitude of matter clustering, exposes inconsistencies between cosmic microwave background data and weak gravitational lensing surveys. The primary goal of this work is to address these tensions by modifying the underlying geometric framework. Specifically, we test two $f(T)$ gravity models using cosmic chronometers, baryonic acoustic oscillations, gamma-ray bursts, and Pantheon+SH0ES datasets, and compare the results with gravitational wave data for validation. Both teleparallel models demonstrate promising performance in simultaneously alleviating the H_0 and S_8 tensions. This work has been done in collaboration with Sai Swagat Mishra , N. S. Kavya, and V. Venkatesha.

Biplob Sarkar

Thermal conduction and thermal-driven winds in magnetized viscous accretion disk dynamics

This paper investigates the effects of saturated thermal conduction (TC) and thermal-driven winds (TDWs) on magnetized advection-dominated accretion onto a rotating black hole (BH). We incorporate dissipative processes in the magnetized accretion flow and expect the accretion disk to be threaded by predominantly toroidal and turbulent magnetic fields. We solve the magnetohydrodynamics equations and construct a self-consistent steady model of the magnetized accretion flow surrounding a rotating BH, which includes TC and TDWs. We seek global accretion solutions spanning from the BH horizon to a large distance and analyze the solution's characteristics as a function of dissipation parameters. Accretion solutions with multiple critical points may exhibit shock waves if they meet the standing shock criteria. We found steady, global transonic, and shocked accretion solutions around the rotating BH. In particular, the wind parameter (m) and the saturated conduction parameter (Φ_s) significantly influence the dynamical behavior of shocks. The shock location moves away from the BH horizon as Φ_s and m increase, assuming fixed conditions at the disk's outer edge. Our formalism explains the declining phase of BH outbursts, characterized by a monotonic decrease in QPO frequency as the burst decays. Based on our findings, we conclude that the combined effect of Φ_s and m parameters substantially alters the steady shock specific energy vs angular momentum parameter space and also modifies the corresponding post-shock luminosity vs QPO frequency parameter space. We propose, based on our theoretical model, that the Φ_s and m parameters may significantly influence the evolution of the BH outbursts. This work has been done in collaboration with Indu Kalpa Dihingia, Ranjeev Misra.

X-Ray Spectral and Temporal Properties of LMXB 4U 1608-52–Observed with AstroSat and NICER

We report results from a detailed study of the neutron star X-ray binary, 4U 1608-52, using observations with AstroSat (Large Area X-ray Proportional Counter/Soft X-ray Telescope) and the Neutron Star Interior Composition Explorer during its 2016 and 2020 outbursts. The 0.7–20.0 keV spectra could be well described with the disk blackbody and thermal Comptonization model. The best-fitting inner disk temperature is $\sim$ 1 keV and radius $\sim 22.17^{+2.57}_{-2.38}$–$27.19^{+2.03}_{-1.85}$ km and no significant evolution was observed in the disk radius after performing flux and time-resolved spectroscopy. We used a multi-Lorentzian approach to fit the power density spectra and obtained broadband noise variability. We estimated the energy-dependent fractional rms and time lag of the broadband noise, and these variations are quantitatively modeled as being due to the coherent variation of the disk emission and the coronal heating rate. Thus, the rapid temporal modeling is consistent with the longer-term spectral evolution where the inner disk radius does not vary, and instead, the variations can

be attributed to accretion rate variations that change the inner disk temperature and the coronal heating rate. This work has been done in collaboration with Sree Bhattacherjee, Ankur Nath, Biplob Sarkar, Aru Beri, Suchismito Chattopadhyay, Yashpal Bhulla and Ranjeev Misra

Asoke K. Sen

Circularly Polarized Light in Kerr Gravitational Field: Its Implication in Spin-Gravity Interaction

Various calculations carried out in the past to understand the propagation of light in a rotating gravitational field (viz., Kerr field) are examined. For a plane-polarized light, it is observed that due to the effect of rotational gravitational field, the polarization vector of light gets rotated, with the amount of rotation independent from the frequency of the light. In the present work, using the formulations of geometrical optics, I try to find the implications of such findings, which seem to be very strange and give rise to violation of Lorentz Invariance and the Equivalence Principle, which are mostly not accepted by present-day physics. The analysis involves splitting plane-polarized light into left and right circularly polarized components, and then one finds that these two components (with a given frequency) travel with two different velocities in the Kerr field. Also, for an individual circularly polarized component, the velocity of propagation depends on the frequency of light. Assuming the two opposite directions of circularly polarized light to represent two opposite photon spin states, the line element for circularly polarized light is found to depend on the photon spin in addition to frequency. Additional calculations are made to estimate the propagation time delay between two circularly polarized components (with given frequency) between the source and observer at finite distances from the Kerr mass. Some typical estimates of this time delay are made for the Sun and one pulsar, so that in the future one can experimentally verify these results. For an individual circularly polarized component, time delay expressions are also derived for the propagation of light at two different frequencies. It has been found that circularly polarized light with higher frequency (energy) travels faster in a rotating gravitational field as compared to its lower frequency counterpart.

Ranjan Sharma

Model of a Static, Spherically Symmetric, Charged Star with Anisotropic Stress and Its Complexity Analysis

Relevance of 'complexity factor' in the studies of relativistic self-gravitating objects has become an area of intense research in recent years. For a stellar configuration, the complexity factor appears as a structure scalar obtained from the orthogonal splitting of the Riemann tensor. The scalar function contains information about all the modifications produced by density inhomogeneity and pressure anisotropy. To investigate the role of various factors contributing to the 'complexity factor' and subsequent occurrence of 'cracking' within a self-gravitating star, we develop a new class of exact solutions to a spherically symmetric and static stellar configuration in the presence of charge and anisotropic pressure. Some of the stellar models studied earlier are shown to be sub-class our solutions. Making use of one particular class of solutions, we analyze the impacts of charge and anisotropic stress on the complexity factor of a given stellar configuration where the complexity factor is interpreted in terms of the definition put forward by Herrera [*Phys. Rev. D* **97** (2018) 44010]. While even in the presence of charge and anisotropic stress of an inhomogeneous stellar configuration the complexity factor might vanish, we show that the complexity factor usually increases in the presence of charge and anisotropy. As the appearance of cracking in a self-gravitating system can be linked to anisotropic stress which in turn leads to non-zero complexity factor, our analysis may provide new insight into the structure and stability of a stellar configuration. This work has been done in collaboration with Arpita Ghosh, Satarupa Barman, and K. Komathiraj.

Compactness bound of Buchdahl-Vaidya-Tikekar anisotropic star in $D \geq 4$ dimensional spacetime

We study the higher dimensional scenario of an anisotropic compact star using the Buchdahl-Vaidya-Tikekar metric ansatz. In our formalism, the anisotropy is assumed in such a way that, in the absence of it, the solution reduces to Schwarzschild's interior solution in $D \geq 4$ dimensions. The model is so developed that it correlates anisotropy to the curvature parameter K which characterizes a departure from spherical geometry of the $t =$ constant hypersurface of the associated spacetime when embedded in a 4 dimensional Euclidean space. Due to the particular choice of anisotropy, the

pressure balancing equation for hydrostatic equilibrium continues to have the same form in higher dimensions. Consequently, our approach permits extending a four-dimensional solution to a higher dimensional spacetime without deforming the sphericity of the configuration. Making use of the model, we propose a higher dimensional anisotropic analogue of the Buchdahl bound on compactness. We show that additional dimension as well as anisotropy reduce the compactness limit. Our technique helps to regain the original Buchdahl limit in $D = 4$ dimensions and also, in the absence of anisotropy, the compactness limit in higher dimensions obtained earlier by Leon and Cruz [Gen. Relativ. Grav. **32** 1207 (2000)]. It turns out that the maximum achievable dimension remains model dependent through the causality condition and the compactness limit. We analyze the model under all the requisite physical conditions for a relativistic anisotropic fluid sphere which might serve as the internal structure of a compact star in higher dimensions. We also analyze the consequences of the departure from homogeneous spherical distribution and dimensionality on the physical behaviour of the star. We note that the EOS becomes stiffer in higher dimensions and comparatively lower anisotropic stress. Our calculation shows that the central density reduces as we move towards higher dimensions and inclusion of anisotropy increases the rate of fall of the density profile. We also note that the two pressures get reduced considerably in higher dimensions. We show that, for a given curvature parameter specifying the sphericity, an extra dimension is analogous to moving towards a homogeneous distribution. This work has been done in collaboration with Samstuti Chanda.

Rathin Sarma

Modelling the energy dependent X-ray variability of Mrk 335

We present a technique which predicts the energy dependent fractional r.m.s for linear correlated variations of a pair of spectral parameters and apply it to an *XMM-Newton* observation of Mrk 335. The broadband X-ray spectrum can be interpreted as a patchy absorber partially covering the primary emission, a warm and hot coronal emission or a relativistically blurred reflection along with the primary emission. The fractional r.m.s has a non-monotonic behavior with energy for segments of lengths 3 and 6 ksecs. For each spectral model, we consider every pair of spectral parameters and fit the predicted r.m.s with the observed ones, to get the pair which provides the best fit. We find that a variation in at least two parameters is required for all spectral interpretations. For both time segments, variations in the covering fraction of the absorber and the primary power law index gives the best result for the partial covering model, while a variation in the normalization and spectral index of the warm component gives the best fit in the two corona interpretation. For the reflection model, the best fit parameters are different for the two time segment lengths, and the results suggests that more than two parameters are required to explain the data. This, combined with the extreme values of emissivity index and reflection fraction parameters obtained from the spectral analysis, indicates that the blurred reflection model might not be a suitable explanation for the Mrk 335 spectrum. We discuss the results as well as the potential of the technique to be applied to other data sets of different AGN. This work has been done in collaboration with K. Akhila, Ranjeev Misra, Savithri H. Ezhikode, and K. Jeena.

Md. Salim Md. Harun Shekh

Dark energy and cosmic evolution: A study in $f(R,T)$ gravity

In the context of f(R,T) gravity theory for the flat Friedmann-Lemaitre-Robertson–Walker (FLRW) model, the accelerating expansion of the universe is investigated using a specific form of the emergent Hubble parameter. Datasets from H(z), Type Ia supernovae (SNIa), and Baryon Acoustic Oscillations (BAO) are used to constrain the model and identify the ideal parameter values in order to evaluate the statistical significance of f(R,T) gravity. The bestfit parameters are derived by solving the modified Friedmann equations through a MCMC analysis. These parameters are used to compute the equation of state, statefinders, energy conditions, and the $(\omega - \omega^{'})$ plane. Furthermore, the evolution of kinematic cosmographic parameters is examined. The findings provide significant behavior and features of dark energy models. Our comprehension of the dynamics and evolution of the universe is improved by this study, which also advances our understanding of dark energy and how it shapes the universe. Also, a key outcome of our study is the demonstration that f(R,T) gravity can account for the Hubble tension through an evolving H0, in agreement with recent findings in modified gravity. Our results provide a

significant contribution to the ongoing discussion of modified gravity models and their role in explaining cosmic acceleration, offering an alternative perspective to the standard ΛCDM paradigm. This work has been done in collaboration with N. Myrzakulov, Anirudh Pradhan, and Archana Dixit

Models of $f(Q)$ Gravity with Electromagnetic Field

There are so many ideas that potentially explain the dark energy phenomenon, current research is focusing on a more in-depth analysis of the potential effects of modified gravity on both local and cosmic scales. In this paper we investigate some cosmic reconstructions in cosmology, where is the nonmetricity corresponding to the evolution background in the Friedmannâ€“LemaÃ®treâ€“Robertsonâ€“Walker (FLRW) universe. This allows us to determine how any FLRW cosmology can emerge from a particular theory. We employ the reconstruction technique to generate explicit formulations of the Lagrangian for several types of matter sources like a perfect fluid, a dustlike fluid, stiff fluid and a binary mixture of two fluids. Furthermore, we compute the field equations and the equation of state (EoS) parameter for two different reconstructed models with variation of the involved constants, which gives a scenario of an accelerating universe, a quintessence region and the cosmological constant. We also observe that the time dependence of admits cosmic acceleration. These new gravity inspired models may have an impact on gravitational phenomena at other cosmological scales.This work has been done in collaboration with H Sohail, I Mahmood, A Ditta, A K. Yadav, S Parekh.

Mohd Shahalam

Evolution of the universe prior to inflation in loop quantum cosmology

We study the dynamics of pre-inflation with the generic potentials, namely, $V(\phi) \propto \phi^4$ and $V(\phi) \propto (1+\phi)^2$ in the context of loop quantum cosmology where initial singularity is resolved by a non-singular quantum bounce. Initially, the background evolution is either dominated by kinetic energy or potential energy at the quantum bounce. In case of kinetic energy dominated evolution at the bounce, we find three generic phases such as bouncing, transition and the slow-roll inflation whereas first two regimes are vanished in case of potential energy dominated evolution though the slow-roll inflation can still be achieved. Therefore, we find the physically viable initial conditions of the inflaton field which have the number of e-folds at least 60 to be compatible with observations. Additionally, we discuss the phase space diagram for the models under consideration where all the trajectories of the inflaton field start from the bounce and move towards the stable attractor points.

Dynamics of pre-inflationary universe in loop quantum cosmology

In this article, we examine the pre-inflationary universe for the potential $V(\phi) \propto \phi^{1.9}$ in the framework of loop quantum cosmology. We choose such type of potential as the quadratic potential is almost disfavored by the Planck 2018 data. We primarily study the initial conditions of the inflaton field that are physically viable and produce the slow-roll inflation. We also obtain the number of e-folds in the slow-roll regime that are consistent with the observations. In addition, we present the phase space analysis and show that the slow-roll inflation is an attractor for a wide range of initial conditions.

Kaushal Sharma

Magnetars as powering sources of gamma-ray burst associated supernovae, and unsupervized clustering of cosmic explosions

We present the semi-analytical light curve modelling of 13 supernovae associated with gamma-ray bursts (GRB-SNe) along with two relativistic broad-lined (Ic-BL) SNe without GRBs association (SNe 2009bb and 2012ap), considering millisecond magnetars as central-engine-based power sources for these events. The bolometric light curves of all 15 SNe in our sample are well-regenerated utilising a χ^2-minimisation code, `MINIM`, and numerous parameters are constrained. The median values of ejecta mass ($M_{\rm ej}$), magnetar's initial spin period ($P_{\rm i}$) and magnetic field (B) for GRB-SNe are determined to be ≈ 5.2 M$_\odot$, 20.5 ms and 20.1×10^{14} G, respectively. We leverage machine learning (ML) algorithms to comprehensively compare the 3-dimensional parameter space encompassing $M_{\rm ej}$, $P_{\rm i}$, and B for GRB-SNe determined herein to those of H-deficient superluminous SNe (SLSNe-I), fast blue optical transients (FBOTs), long GRBs (LGRBs), and short GRBs (SGRBs) obtained from the literature. The application of unsupervised ML clustering algorithms on the parameters $M_{\rm ej}$, $P_{\rm i}$, and B for GRB-SNe, SLSNe-I, and FBOTs yields a classification accuracy of

~95%. Extending these methods to classify GRB-SNe, SLSNe-I, LGRBs, and SGRBs based on $P_{\rm i}$ and B values results in an accuracy of ~84%. Our investigations show that GRB-SNe and relativistic Ic-BL SNe presented in this study occupy different parameter spaces for $M_{\rm ej}$, $P_{\rm i}$, and B than those of SLSNe-I, FBOTs, LGRBs and SGRBs. This indicates that magnetars with different $P_{\rm i}$ and B can give birth to distinct types of transients. This work has been done in collaboration with Amit Kumar, Jozsef Vinkó, Danny Steeghs et al.

Prerana Sharma

Cosmic-Ray-driven Thermal Modes in Partially Ionized Viscous Plasma with Hall Current

This research investigates the dynamics of cosmic-ray-driven thermal modes within a partially ionized plasma permeated by a magnetic field. A two-fluid model is adopted to capture the intricate physics arising from the presence of neutral dynamics. The ion–cosmic fluid is described using a nonideal magnetohydrodynamic framework, incorporating ion and neutral viscosities, the Hall current, and ion–neutral collisions. Neutral dynamics are characterized by neutral viscosity, pressure, and collisional interactions. The derived general dispersion relation reveals two dominant modes: a collisional neutral thermal viscous mode and a Hall-modified cosmic magnetothermal viscous mode. The domains of instability for the neutral thermal viscous mode are determined, while the stability of the ion–cosmic thermal viscous mode is assessed using the Routh–Hurwitz criterion, yielding critical lengths for isochoric, isobaric, and isentropic modes. In the collisional regime, a seventh-order dispersion relation is derived and analyzed numerically. Next, the second dominant mode of the general dispersion relation is further analyzed in both transverse and longitudinal directions relative to the magnetic field. In the transverse direction, a seventh-order collisional cosmic magnetothermal viscous mode is obtained, influenced by ion and neutral viscosities, the diffusion coefficient, collisions, and the cosmic and ion acoustic speeds. This mode is further investigated analytically and numerically. Numerical estimates demonstrate that the diffusion coefficient and cosmic pressure enhance the growth rate of thermal modes. The critical wavelength of the magnetothermal cosmic mode is calculated. In the longitudinal direction, the obtained modes exhibit no substantial cosmic influence, but instead represent Hall-modified collisional Alfvén waves. This work has been done in collaboration with Shweta Jain.

Modulation of self-focusing and plasma wave dynamics by ripple on hollow gaussian beams

This study investigates the propagation of a hollow Gaussian beam (HGB) through a collisionless plasma medium containing superimposed ripples, incorporating relativistic nonlinear effects. The Wentzel-Kramers-Brillouin (WKB) paraxial ray approximation and the eikonal method are employed to derive governing equations for the self-focusing of the main beam, the ripples, and the excitation of plasma waves under these conditions. Our analysis demonstrates that the presence of ripples significantly alters the propagation dynamics of HGBs and influences the excitation of electron plasma waves (EPWs). The order and phase angle of ripples influence the main beam dynamics and EPW propagation. Both the HGB order and ripple order affect the ripple dynamics and EPW power. The various orders of the HGB and the angle between the ripple and the main beam affect the ripple's focusing behavior. These factors collectively influence the intensity of the excited plasma wave. Our findings contribute to a deeper understanding of laser-plasma interactions involving pre-existing ripples on HGB. This work has been done in collaboration with Keshav Walia.

Ashutosh Singh

Dynamical systems of modified Gauss–Bonnet gravity: cosmological implications

In this paper, we derive the field equations of modified Gauss-Bonnet gravity termed as $f(R,G)$ gravity for the non-flat Friedmann-Robertson-Walker (FRW) spacetime. We utilize the dynamical system approach to study the cosmic dynamics of two different class of $f(R,G)$ models composed of radiation and matter (cold dark matter and baryonic matter). The linear perturbations around the fixed points are studied to explore the corresponding stability of points. The cosmological implications are studied in $f(R,G) = f_0 R^n G^{1-n}$ and $f(R,G) = f_0 R^\alpha + f_1 G^\beta$ models to identify the qualitative evolution of universe with the flat-FRW spacetime. The qualitative differences between the considered class of models are discussed in detail. The fixed points corresponding to the late-time accelerated and radiation phase of the universe will exist in the model but, the existence of fixed point

corresponding to the matter dominated phase will depend on the functional form of $f(R, G)$. Furthermore, the autonomous systems are utilized to study the cosmographic parameters along with the statefinder diagnostic.

Observational constraints on the expansion scalar and shear relation in the Locally rotationally symmetric Bianchi I model

We consider the universe composed of radiation, matter, and vacuum energy in the axially symmetric Bianchi I spacetime background. In this framework, the assumption 'shear scalar proportional to the expansion scalar' leading to a relation between directional scale factors has been probed for its observational compatibility with the data of different origins. The phase space of the model parameters is determined through the Bayesian Monte Carlo method. The precise observational bounds on parameters including n have been obtained with the cosmic chronometer, baryonic acoustic oscillations, cosmic microwave background, and the Supernovae Ia Pantheon data. The results are then compared with the results obtained by using the Pantheon+SH0ES data and the combined data sets. The deviations of n from unity change the cosmic dynamics during the early and late time universe also, as compared to the Λ cold dark matter model. We also discuss the information criterion in the model. This work has been done in collaboration with S. Mandal, R. Chaubey, and R. Raushan.

Dharm Veer Singh

Non-perturbative correction on the black hole geometry

In this paper, we use the holographic principle to obtain a modified metric of black holes that reproduces the exponentially corrected entropy. The exponential correction of the black hole entropy comes from non-perturbative corrections. It interprets as a quantum effect which affects black hole thermodynamics especially in the infinitesimal scales. Hence, it may affect black hole stability at the final stage. Then, we study modified thermodynamics due to the non-perturbative corrections and calculate thermodynamics quantities of several non-rotating black holes. This work has been done in collaboration with Behnam Pourhassan, Hoda Farahani, Farideh Kazemian, Izzet Sakallı, and Sudhaker Upadhyay.

Thermodynamics of a newly constructed black hole coupled with nonlinear electrodynamics and cloud of strings

This paper finds an exact singular black hole solution in the presence of nonlinear electrodynamics as the source of matter field surrounded by a cloud of strings in 4D AdS spacetime. Here, the presence of the cloud of string, the usual Bardeen solution, becomes singular. The obtained black hole solution interpolates with the AdS Letelier black hole in the absence of both the deviation parameter and magnetic charge and interpolates with the AdS Bardeen black hole in the absence of the deviation parameter and a cloud of strings parameter. We analyse the horizon structure and thermodynamics properties, including the stability of the resulting black hole, numerically and graphically. Thermodynamical quantities associated with the black hole get modified due to the nonlinear electrodynamics and cloud of strings. Moreover, we study the effect of a cloud of strings parameter, magnetic charge and deviation parameter on critical points and phase transition of the obtained black hole where the cosmological constant is treated as the thermodynamics pressure. The critical radius increases with increasing deviation parameter values and magnetic charge values. In contrast, the critical pressure and temperature decrease with increasing deviation parameters and magnetic charge values. This work has been done in collaboration with Himanshu Kumar Sudhanshu, and Sudhaker Upadhyay.

Gyan P. Singh

Cosmological model with linear equation of state parameter in $f(R, L_m)$ gravity

In this paper, we examine the universe's expansion in $f(R, L_m)$ gravity for a particular form of $f(R, L_m) = \frac{R}{2} + L_m^n$. The field equations for flat FLRW metric with matter Lagrangian $L_m = \rho$ are derive. Hubble parameter in terms of red-shift(z) are derived using the linear form of Equation of State (EoS) parameter $\omega = w_0 + w_1 z$. By using Bayesian statistical techniques based on χ^2-minimization technique, we have obtained the best fit values of the model parameters of this model for cosmic chronometer and supernovae Pantheon datasets. The evolution of the equation of state parameter(ω), energy density (ρ), pressure (p) cosmographic parameters, and the impact of the energy conditions with best-fit values of the model parameters are all thoroughly examined. We have also analyze Om diagnostic's behavior and determine the present age of

universe for this model. This work has been done in collaboration with Romanshu garg, , Ashwini R. Lalke, and Saibal Ray.

A generalized ΛCDM model with parameterized Hubble parameter in particle creation, viscous and $f(R)$ model framework

In this study, we construct a theoretical framework based on the generalized Hubble parameter form which may arise within the particle creation, viscous and $f(R)$ gravity theory. The Hubble parameter is scrutinized for its compatibility with the observational data relevant to the late-time universe. By using Bayesian statistical techniques based on χ^2 minimization method, we determine model parameters's best fit values for the cosmic chronometer and supernovae Pantheon datasets. For the best fit values, the cosmographic and physical parameters are analyzed to understand the cosmic dynamics in model. We also analyze the model section criterion in comparison to the Λ cold dark matter model. This work has been done in collaboration with Romanshu Garg.

Newton Singh

Conservative wormholes in generalized $\hat{I}^{o}(R,T)$-function

We present an exhaustive study of wormhole configurations in $\kappa(\mathcal{R},\mathcal{T})$ gravity with linear and non-linear functions. The model assumed Morris-Thorne spacetime where the redshift and shape functions linked with the matter contain and geometry of the spacetime through non-covariant conservation equation of the stress-energy tensor. The first solution was explored assuming a constant redshift function that leads to a wormhole (WH) which is asymptotically non-flat. The remaining solutions were explored in two cases. Firstly, assuming a linear equation of state $p(r) = \omega\rho(r)$ along with different forms of $\kappa(\mathcal{R},\mathcal{T})-$function. This proved enough to derive a shape function of the form $b(r) = r_0\left(\frac{r_0}{r}\right)^{1/\omega}$. Secondly, by assuming specific choices of the shape function consistent with the wormhole configuration requirements. All the solutions fulfill flare-out condition, asymptotically flat and supported by phantom energy. Further, the embedding surface and its revolution has been generated using numerical method to see how the length of the throat is affected of the coupling parameters through $\kappa(\mathcal{R},\mathcal{T})$ function. At the end, we have also calculated the average null energy condition, which is satisfied by all the WH models signifying minimum exotic matter is required to open the WH throats. This work has been done in collaboration with G. R. P. Teruel, S. K. Maurya, Tanmoy Chowdhury, and Farook Rahaman.

A comparative study of embedding class one, conformally flat, vanishing complexity factor and conformally symmetric solutions and their impacts on compact star structure

For the first time, we have presented in detail the comparative studies of embedding class one (CO), conformally flat (CF), vanishing complexity factor (COM), and conformally symmetric (CS) solutions, which are the easiest way of exploring new solutions of the field equations. All these solutions simplify the two metric potentials problem to one metric potential through specific bridge equations. To compare on the same footing, we have assumed the same g_{rr} metric function and solved the g_{tt} metric functions via the bridge equations. We then compare all the physical quantities like density, pressure, anisotropy, adiabatic index, etc. To check which type of matter is appropriate for these solutions, we have plotted the equation of states (EoSs) and found the best-fitted functions. We have found that CO solution obeys quadratic EoS, the COM solution best fits with linear EoS, CF solution contains normal and exotic matters, while the CS solution follows a cubic polynomial, and also includes normal, stiff, and exotic matters. In the end, we have plotted the $M-R$ curves and fitted them with observed masses of a few neutron stars to predict their radii. This work has been done in collaboration with , S. K. Maurya, Satyanarayan Gedela , and Ravindra K. Bish.

Monika Sinha

Universal relations for compact stars with exotic degrees of freedom

The nature of the highly dense matter inside the supernova remnant compact star is not constrained by terrestrial experiments and hence modeled phenomenologically to accommodate the astrophysical observations from compact stars. The observable properties of the compact stars are highly sensitive to the microscopic model of highly dense matter. However, some universal relations exist between some macroscopic properties of compact stars independent of the matter model. We study the universal relation including the

stars containing exotic degrees of freedom such as heavier strange and non-strange baryons, strange quark matter in normal and superconducting phases, etc. We examine the universal relations for quantities moment of inertia - tidal love number - quadrupole moment. We also study the correlation of non-radial f-mode and p-mode frequencies with stellar properties.We find the f-mode frequency observes the universal relation with dimensionless tidal deformability but the p-mode frequency does not show a good correlation with stellar properties. The p-mode frequency is sensitive to the composition of the matter. We find that universal relation is also applicable for stars with exotic matter in the core of the star with several models of exotic matter. This work has been done in collaboration with Anil Kumar, Manoj Kumar Ghosh,et al.

Non-radial oscillations in newly born compact star considering effects of phase transition

The massive stars end their lives by supernova explosions leaving central compact objects that may evolve into neutron stars. Initially, after birth, the star remains hot and gradually cools down. We explore the matter and star properties during this initial stage of the compact stars considering the possibility of the appearance of deconfined quark matter in the core of the star. At the initial stage after the supernova explosion, the occurrence of non-radial oscillation in the newly born compact object is highly possible. Non-radial oscillations are an important source of gra vitational wa ves (GWs). There is a high chance for GWs from these oscillations, especially the nodeless fundamental (f) mode to be detected by next-generation GW detectors. We study the evolution in frequencies of non-radial oscillation after birth considering phase transition and predicting the possible signature for different possibilities of theoretical compact star models. This work has been done in collaboration with Anil Kumar,and Pratik Thakur.

Parijat Thakur

2017 Outburst of H 1743-322: AstroSat and Swift View

We perform a comprehensive timing and broadband spectral analysis using an AstroSat observation of the low-mass black hole X-ray binary H 1743-322 during its 2017 outburst. Additionally, we use two Swift/XRT observations, one of which is simultaneous with AstroSat and the other taken three days earlier, for timing analysis. The hardness-intensity diagram indicates that the 2017 outburst was a failed one, unlike the previous successful outburst in 2016. We detect type C quasi-periodic oscillation (QPO) in the simultaneous AstroSat and Swift/XRT observations at ∼0.4 Hz, whereas an upper harmonic is noticed at ∼0.9 Hz in the AstroSat data only. Although these features are found to be energy-independent, we notice a shift of ∼0.08 Hz in the QPO frequency over the interval of three days. We also investigate the nature of variability in the two consecutive failed outbursts in 2017 and 2018. We detect soft time lags of 23.2 ± 12.2 ms and 140 ± 80 ms at the type C QPO frequencies in 2017 AstroSat and 2018 XMM-Newton data, respectively. The lag-energy spectra from both the outbursts suggest that the soft lags may be associated with reflection features. The broadband spectral analysis indicates that the source was in the low/hard state during the AstroSat observation. Modeling of the disk and reflection continuum suggests the presence of an accretion disk that is significantly truncated by at least $27.4r_g$ from the innermost stable circular orbit when the source luminosity is ∼1.6% of the Eddington luminosity. This work has been done in collaboration with Pragati Sahu, Swadesh Chand, Parijat Thakur, and G. C. Dewangan et al.

Transit timing variations of the sub-Saturn exoplanet HAT-P-12b

We present Transit Timing Variations (TTVs) of HAT-P-12b, a low-density sub-Saturn mass planet orbiting a metal-poor K4 dwarf star. Using 14 years of observational data (2009â€“2022), our study incorporates 7 new ground-based photometric transit observations, three sectors of Transiting Exoplanet Survey Satellite (TESS) data, and 23 previously published light curves. A total of 46 light curves were analyzed using various analytical models, such as linear, orbital decay, apsidal precession, and sinusoidal models to investigate the presence of additional planets. The stellar tidal quality factor ($Q'_* \sim 28.4$) is lower than the theoretical predictions, making the orbital decay model an unlikely explanation. The apsidal precession model with a χ^2_r of 4.2 revealed a slight orbital eccentricity (e = 0.0013) and a precession rate of 0.0045 rad/epoch. Frequency analysis using the Generalized Lombâ€“Scargle (GLS) periodogram identified a significant periodic signal at 0.00415 cycles/day (FAP = 5.1×10^{-6} %), suggesting the influence of an additional planetary companion. The sinusoidal model provides the lowest reduced

chi-squared value (χ^2_τ) of 3.2. Sinusoidal fitting of the timing residuals estimated this companion to have a mass of approximately 0.02 M_J, assuming it is in a 2:1 Mean-Motion Resonance (MMR) with HAT-P-12b. Additionally, the Applegate mechanism, with an amplitude much smaller than the observed TTV amplitude of 156 s, confirms that stellar activity is not responsible for the observed variations.This work has been done in collaboration with Kaviya Parthasarathy, Hsin-Min Liu, and Ing-Guey Jian et al.

Vivek Baruah Thapa

Bayesian Inference of dense matter equation of state of neutron star with antikaon condensation

In this paper, we employ the Density Dependent Relativistic Hadron (DDRH) field theoretical Model in a Bayesian analysis to investigate the equation of state (EOS) of dense matter featuring antikaon condensation for K^- and $\bar{K}^0$ inside neutron stars. The vector coupling parameters within the kaonic sector are determined through the iso-spin counting rule and quark model. Our study integrates various constraints, including χEFT calculations, nuclear saturation properties, and astrophysical observations from pulsars PSR J0030+0451, PSR J0740+66, and the GW170817 event. We present posterior distributions of model parameters derived from these constraints, enabling us to explore the distributions of nuclear matter properties and neutron star (NS) characteristics such as radii, tidal deformabilities, central energy densities, and speed of sound. The antikaon potential at the 68(90)% confidence intervals is determined to be $-129.36^{+12.53(+32.617)}_{-3.837(-5.696)}$ MeV. This aligns with several studies providing estimates within the range of -120 to -150 MeV. We find that the maximum neutron star mass is constrained to around $2M_\odot$ due to the significant softening of the EOS caused by antikaon condensation. This softening results in a considerable decrease in the speed of sound. Although antikaon condensation for K^- is not feasible inside the canonical neutron stars, it becomes feasible for higher NS masses. The condensation of both K^- and $\bar{K}^0$ is probable to be present in the interior of neutron star with mass greater than $2M_\odot$. We also discuss the interconnections among input variables, isoscalar and isovector aspects of the EOS, and specific NS properties in the context of antikaon condensation. This work has been done in collaboration with Vishal Parmar, Anil Kumar, Debades Bandyopadhyay,and Monika Sinha

Exploring non-radial oscillation modes in dark matter admixed neutron stars

Because of their extreme densities and consequently, gravitational potential, compact objects such as neutron stars can prove to be excellent captors of dark matter particles. Considering purely gravitational interactions between dark and hadronic matter, we construct dark matter admixed stars composed of two-fluid matter subject to current astrophysical constraints on maximum mass and tidal deformability. We choose a wide range of parameters to construct the dark matter equation of state, and the DDME2 parameterization for the hadronic equation of state. We then examine the effect of dark matter on the stellar structure, tidal deformability and non-radial modes considering the relativistic Cowling approximation. We find the effect on p-modes is substantial, with frequencies decreasing up to the typical $f-$mode frequency range for most stars with a dark matter halo. The effects on the $f-$mode frequency are less extreme. Finally, we find the most probable values of the dark matter parameters that satisfy the observational constraints. This work has been done in collaboration with Pratik Thakur, Anil Kumar, Vishal Parmar, and Monika Sinha.

S. K. Tripathy

Scalar eld induced dynamical evolution in teleparallel gravity

In this paper, we investigate the role of scalar field potentials in the dynamical evolution of the Universe. A gravity theory with a non-minimally coupled scalar field with torsion in the geometrical action simulating effective dark energy is considered to study an extended matter bounce scenario. The dynamical behaviour of the equation of state parameter has been studied near the bouncing epoch. Keeping in mind the inflationary behaviour near the bounce, five different scalar field potential functions are explored, and their effect on the equation of state parameter is investigated. This work has been done in collaboration with B. Mishra, and S. A. Kadam.

Non-minimally coupled teleparallel scalar field reconstruction of matter bounce scenario

Teleparallel description of gravity theories where the gravity is mediated through the tetrad field and consequent torsion provide an alternative route to explain the late time cosmic speed up issue.

Generalisation of the teleparallel gravity theory with different functional forms of the torsion scalar T leads to $f(T)$ gravity. The role of scalar field played in addressing issues in cosmology and astrophysics has developed an interest in the inclusion of a scalar field along with an interaction potential in the action. Such a generalised gravity theory is dubbed as $f(T, \phi)$ theory. We have explored such a gravity theory to reconstruct the interaction potential of the scalar field required for an extended matter bounce scenario. The cosmological implications of the reconstructed scalar field potential are studied considering two viable and well known functional forms of $f(T, \phi)$. The energy conditions of these model are discussed to assess the viability of the cosmological models. This work has been done in collaboration with Sasmita Pal.

Jithesh V

Chandra X-ray Analysis of Herbig Ae/Be Stars

Herbig Ae/Be (HAeBe) stars are intermediate-mass pre-main sequence stars, characterized by infrared excess and emission lines. They are observed to emit X-rays, whose origin is a matter of discussion and not settled yet. X-ray emission is not expected in HAeBe stars, as they lack the sub-surface convective zone. In this study, we retrieved observations from the *Chandra* archive for 62 HAeBe stars, among which 44 sources (detection fraction ∼71%) were detected in X-rays, with 7 being new detections. We use this sample as a test bed to conduct a comparative analysis of the X-ray properties of HAeBe stars and their low-mass counterparts, T Tauri Stars (TTSs). Further, we compare the X-ray properties of HAeBe stars and TTSs with optical and IR properties to constrain the X-ray emission mechanism in HAeBe stars. We found no correlation between X-ray emission and disk properties of HAeBe stars, confirming that X-rays are not related to accretion shocks. About 56% of HAeBe stars without any known sub-arcsec companions have lower plasma temperatures (kT $\leq$ 2 keV). We observe flaring/variability in HAeBe stars with confirmed low-mass companions. These stars show plasma temperatures $>$ 2 keV, similar to TTSs. Guided by this information we discuss the role of a T Tauri companion for X-ray emission seen in our sample of HAeBe stars. From the results obtained in this paper, we suggest that X-ray emission from HAeBe stars may not be related to accretion shocks or hidden TTS, but rather can be due to magnetically driven coronal emission. This work has been done in collaboration with Hema Anilkumar, Blesson Mathew,and Sreeja S. Kartha et al.

Serendipitous detection of an intense X-ray flare in the weak-line T Tauri star KM Ori with SRG/eROSITA

Weak-line T Tauri stars (WTTS) exhibit X-ray flares, likely resulting from magnetic reconnection that heats the stellar plasma to very high temperatures. These flares are difficult to identify through targeted observations. Here, we report the serendipitous detection of the brightest X-ray flaring state of KM Ori in the eROSITA DR1 survey. Observations from SRG/eROSITA, *Chandra X-ray Observatory*, and *XMM-Newton* are analysed to assess the X-ray properties of KM Ori, thereby establishing its flaring state at the eROSITA epoch. The long-term (1999–2020) X-ray light curve generated for the Chandra observations confirmed that eROSITA captured the source at its highest X-ray flaring state recorded to date. Multi-instrument observations support the X-ray flaring state of the source, with time-averaged X-ray luminosity ($L_{0.2-5\ \mathrm{keV}}$) reaching $\sim 1.9 \times 10^{32}$erg s^{-1} at the eROSITA epoch, marking it the brightest and possibly the longest flare observed to date. Such intense X-ray flares have been detected only in a few WTTS. The X-ray spectral analysis unveils the presence of multiple thermal plasma components at all epochs. The notably high luminosity ($L_{0.5-8\ \mathrm{keV}} \sim 10^{32}$ erg s^{-1}), energy ($E_{0.5-8\ \mathrm{keV}} \sim 10^{37}$ erg), and the elevated emission measures of the thermal components in the eROSITA epoch indicate a superflare/megaflare state of KM Ori. Additionally, the Hα line equivalent width of ∼-5 Å from our optical spectral analysis, combined with the lack of infrared excess in the spectral energy distribution, were used to re-confirm the WTTS (thin disk/disk-less) classification of the source. The long-duration flare of KM Ori observed by eROSITA indicates the possibility of a slow-rise top-flat flare. The detection demonstrates the potential of eROSITA to uncover such rare, transient events, thereby providing new insights into the X-ray activity of WTTS. This work has been done in collaboration with Savithri H. Ezhikode, Hema Anilkumar, R. Arun, Blesson Mathew et al.

Murli M. Verma

Probing massive gravitons in f(R) with lensed gravitational waves

We investigate the novel features of gravitational wave solutions in $f(R)$ gravity under proper gauge considerations in the shifted Ricci scalar background curvature (R1+ϵ). The solution is further explored to study the modified dispersion relations for massive modes at local scales and to derive constraints on ϵ. Our analysis yields new insights as we scrutinize these dispersion effects on the polarization (modified Newman-Penrose content) and lensing properties of gravitational waves. It is discovered that the existing longitudinal scalar mode, and transverse breathing scalar mode are both independent of the mass parameter for $\epsilon << 1$. Further, by analysing the lensing amplification factor for the point mass lens model, we show that lensing of gravitational wave is highly sensitive to these dispersion effects in the milli-Hertz frequency (wave optics regime). It is expected that ultra-light modes, having mass about O(10-15) eV for $\epsilon << (10 - 7)$ lensed by $(103 \leq M_{Lens} \leq 106)M\odot$ compact objects are likely to be detected by the advanced gravitational wave space-borne detectors, particularly within LISA's (The Laser Interferometer Space Antenna) sensitivity band. This work has been done in collaboration with Sharma, Vipin Kumar , Harikumar, Sreekanth ; Grespan, Margherita ; Biesiad.

Surender Verma

On Lepton Flavor Violation and Dark Matter in Scotogenic model with Trimaximal Mixing

We examine the Scotogenic model employing the TM_2 mixing matrix, U_{TM_2}, for neutrinos and parameterize the Yukawa coupling matrix y based on the diagonalization condition for the neutrino mass matrix, m_ν. Our investigation centers on analyzing the relic density of cold dark matter (Ωh^2) and possible lepton flavor violation (LFV) in the model. In particular, we study coannihilation dynamics and LFV, in the model, considering various coannihilation scenarios including non-zero mass splitting between lightest sterile neutrinos. While analyzing, we have taken into consideration respective experimental constraints on Ωh^2 and LFV alongside neutrino oscillation data. Our study reveals that in both normal and inverted hierarchy of neutrino masses, splitting between masses of N_1 and N_2 can be up to $\approx$ 15% for the model to be in consonance with the above constraints. In the second part, we have extended the analysis incorporating extended magic symmetry in m_ν enabling us to completely determine Yukawa coupling matrix (y). We observe a notable exclusion of the effective Majorana mass $|m_{ee}|$ parameter space by cosmological bound on sum of neutrino masses, particularly in the normal hierarchy while inverted hierarchy scenario is excluded due to constraints coming from extended magic symmetry. These findings shed light on the interplay among the Scotogenic model, TM_2 mixing, and extended magic symmetry, offering insights into the permitted parameter space and hierarchy exclusion.This work has been done in collaboration with Tapender, and Sanjeev Kumar.

Minimal Type-I Dirac seesaw and Leptogenesis under A_4 modular invariance

We present a Dirac mass model based on A_4 modular symmetry within Type-I seesaw framework. This extension of Standard Model requires three right-handed neutrinos and three heavy Dirac fermions superfields, all singlet under $SU(2)_L$ symmetry. The scalar sector is extended by the inclusion of a $SU(2)_L$ singlet superfield, χ. Here, the modular symmetry plays a crucial role as the Yukawa couplings acquire modular forms, which are expressed in terms of Dedekind eta function $\eta(\tau)$. Therefore, the Yukawa couplings follow transformations akin to other matter fields, thereby obviating the necessity of additional flavon fields. The acquisition of *vev* by complex modulus τ leads to the breaking of A_4 modular symmetry. We have obtained predictions on neutrino oscillation parameters, for example, the normal hierarchy for the neutrino mass spectrum. Furthermore, we find that heavy Dirac fermions, in our model, can decay to produce observed baryon asymmetry of the Universe through Dirac leptogenesis. This work has been done in collaboration with Labh Singh,and Monal Kashav.

Nilkanth Vagshette

Sloshing and spiral structures breeding a putative radio mini-halo in the environment of a cool-core cluster, Abell 795

Spiral structures and cold fronts in X-rays are frequently observed in cool-core galaxy clusters. However, studies on radio mini-haloes associated with such spirals and their physical connections are rare. Here, we present the detection of an extended diffuse radio emission

entrained in the X-ray spiral structure in a known cool-core cluster, Abell 795. Though the cool core is a sign of the relaxed nature, our re-analysed 30 ks Chandra X-ray data of Abell 795 confirm the presence of an interesting log spiral structure of an X-ray deficit region complemented by an X-ray excess counter spiral in the residual map, exposing its dynamical activity. Our new analysis of 150- and 325 MHz Giant Metrewave Radio Telescope archival data confirms the detection of a ∼180 kpc ultra-steep ($\alpha \sim$ â^'2.7) diffuse radio structure, previously reported as a candidate radio mini-halo from low-sensitive survey maps. This emission spans the entire spiral structure, enclosed by two previously reported cold fronts. Furthermore, optical spectra from the Sloan Digital Sky Survey Data Release 13 and far-ultraviolet data from the Galaxy Evolution Explorer show a considerably low total star formation rate of 2.52 $M_{\odot}$ $yr^{\hat{}'1}$ with no significant variation in metallicity distribution. We argue that the two-phase (hot and cold) plasma at the core with differential velocity has plausibly caused the spiral formation and has redistributed the secondary electrons from the brightest cluster galaxy or the pre-accelerated electrons, which have been (re-)accelerated by the sloshing turbulence to form the observed candidate radio mini-halo structure. This is supported by a few previous studies indicating that spiral formation and sloshing turbulence quenches star formation and facilitates smooth metallicity distribution by mixing the gas in the core. This work has been done in collaboration with S. K. Kadam, Sameer Salunkhe, Surajit Paul, Satish S. Sonkamble, P. K. Pawar, and M. K. Patil.

Sloshing cold fronts in galaxy cluster Abell 2566

This paper presents properties of the intracluster medium (ICM) in the environment of a cool core cluster Abell 2566 (redshift z = 0.08247) based on the analysis of 20 ks Chandra X-ray data. 2D imaging analysis of the Chandra data from this cluster revealed spiral structures in the morphology of X-ray emission from within the central 109 kpc formed due to gas sloshing. This analysis also witness sharp edges in the surface brightness distribution along the south-east and north-west of the X-ray peaks at 41.6 kpc and 77.4 kpc, respectively. Spectral analysis of 0.5 â€“ 7 keV X-ray photons along these discontinuities exhibited sharp temperature jumps from 2.3 to 3.1 keV and 1.8 to 2.8 keV, respectively, with consistency in the pressure profiles, implying their association with cold fronts due to gas sloshing of the gas. Further confirmation for such an association was provided by the deprojected broken power-law density function fit to the surface brightness distribution along these wedge shaped sectorial regions. This study also witness an offset of 4.6" (6.8 kpc) between the BCG and the X-ray peak, and interaction of the BCG with a sub-system in the central region, pointing towards the origin of the spiral structure due to a minor merger. This work has been done in collaboration with S. K. Kadam, Satish S. Sonkamble, M. K. Patil.

Nitin Yadav

Vortex Dynamics in Various Solar Magnetic Field Configurations

We investigate vortex dynamics in three magnetic regions, viz., Quiet Sun, Weak Plage, and Strong Plage, using realistic three-dimensional simulations from a comprehensive radiation-MHD code, MURaM. We find that the spatial extents and spatial distribution of vortices vary for different setups even though the photospheric turbulence responsible for generating vortices has similar profiles for all three regions. We investigate kinetic and magnetic swirling strength and find them consistent with the Alfvén wave propagation. Using a flux tube expansion model and linear magnetohydrodynamics (MHD) wave theory, we find that the deviation in kinetic swirling strength from the theoretically expected value is the highest for the Strong Plage, least for the Weak Plage, and intermediate for the Quiet Sun at chromospheric heights. It suggests that Weak Plage is the most favoured region for chromospheric swirls, though they are of smaller spatial extents than in Quiet Sun. We also conjecture that vortex interactions within a single flux tube in Strong Plage lead to an energy cascade from larger to smaller vortices that further result in much lower values of kinetic swirling strength than other regions. Fourier spectra of horizontal magnetic fields at 1 Mm height also show the steep cascade from large to smaller scales for Strong Plage. These findings indicate the potential of vortex-induced torsional Alfvén waves to travel higher in the atmosphere without damping for weaker magnetic regions such as the Quiet Sun, whereas vortices would result in dissipation and heating due to the vortex interactions in narrow flux tubes for the strongly magnetized regions such as Strong Plage. This work has been done in collaboration with A. Kannan.

Wave transformations near a coronal magnetic null-point

Null points are often invoked in studies of quasi-periodic coronal jets, and in connection with periodic signals preceding actual reconnection events. Although the periodicity of such events spans a large range of periods, most show 2-5 minute periodicity compatible with the global p-modes. We aim to investigate the viability of MHD waves, in particular acoustic p-modes, in causing strong current accumulation at the null points. This can in turn drive localized periodic heating in the solar corona. To reach this goal, we begin with a three-dimensional numerical setup incorporating a gravitationally stratified solar atmosphere and an axially symmetric magnetic field including a coronal magnetic null point. To excite waves, we employ wave drivers mimicking global p-modes. Using our recently developed wave mode decomposition technique, we investigate the process of mode conversion, mode transmission, and wave reflection at various important layers of the solar atmosphere, such as the Alfvén acoustic equipartition layer and transition region. We examine the energy flux distribution among various MHD modes or among acoustic and magnetic components, as the waves propagate and interact with a magnetic field of null topology. We also examine current accumulation in the surroundings of the null point. We found that most of the vertical velocity transmits through the Alfvén acoustic equipartition layer maintaining an acoustic nature while a small fraction generates fast waves via the mode conversion process. The fast waves undergo almost total reflection at the transition region due to sharp gradients in density and Alfvén speed. There are only weak signatures of Alfvén wave generation near the transition region due to fast-to-Alfvén mode conversion. Since the slow waves propagate with the local sound speed, they are not much affected by the density gradients at the transition region and undergo secondary mode conversion and transmission at the Alfvén-acoustic equipartition layer surrounding the null point, leading to fast wave focusing at the null point. These fast waves have associated perturbations in current density, showing oscillatory signatures compatible with the second harmonic of the driving frequency which could result in resistive heating and enhanced intensity in the presence of finite resistivity. We conclude that MHD waves could be a potential source for oscillatory current dissipation around the magnetic null point. We conjecture that besides oscillatory magnetic reconnection, global p-modes could lead to the formation of various quasi-periodic energetic events.

IUCAA CENTRES FOR ASTRONOMY RESEARCH AND DEVELOPMENT (ICARDs)

**Department of Physics,
Assam University (A Central University),
Silchar**

Coordinator:
Professor Himadri Sekhar Das

Areas of research

The ICARD is engaged in advanced research in astrophysics, with a primary focus on photopolarimetric and polarimetric studies. The key research areas at ICARD include:

(i) Photopolarimetric Studies of Star-Forming Clouds

(ii) Polarimetric Studies of Small Bodies in the Solar System

(iii) Observational Studies Using Leading Indian Observatories

(iv) Dust Scattering Simulations

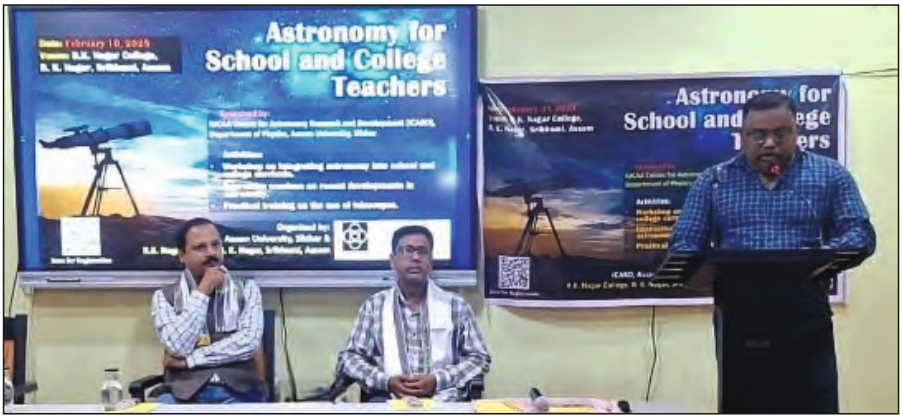
Through these research initiatives, ICARD continues to contribute significantly to the field of astrophysics, fostering collaborations and providing a platform for cutting-edge discoveries in astronomy and space sciences.

Brief report (a paragraph) about the research work done in ICARD:

At ICARD, research activities have primarily focused on the analysis of polarimetric images of comets, asteroids, and molecular clouds using the IRAF software package. These observations aim to investigate the scattering properties and polarization behavior of various celestial bodies. The computational laboratory of the Department of Physics, Assam University, Silchar has been actively utilized to carry out data reduction, simulation, and modeling tasks related to these studies. Notably, the Umov effect in polydisperse dust aggregates has been explored using the available computational facilities, contributing to the understanding of light scattering phenomena in astrophysical dust environments.

List any workshops/schools organised by ICARD

One-Day Workshop on Astronomy Popularization at PDUAM, Eraligool, Sribhumi, Assam on Feb 12, 2025.



One-Day Workshop on Astronomy for Teachers at Ramkrishnanagar College, Sribhumi, Assam on February 22, 2025.

One-Day Workshop on Astronomy for College Students at Karimganj College, Sribhumi, Assam on February 22, 2025.

Outreach program (including public lectures / sky watch) organised by ICARD

Key Outreach Activities

I) Inauguration and School Outreach (November 2024)

ICARD commenced its journey in November 2024 with a series of astronomy outreach programs targeting schools and colleges. Government and private institutions visited the Department of Physics, where students participated in engaging discussions, attended lectures by ICARD scholars, and observed celestial wonders through the observatory's telescopes. Notable events included:

- **12th November 2024**: Students from Saint Capitanio School, Silchar visited ICARD, participating in hands-on activities and telescope observations.
- **21st November 2024**: Students from Kendriya Vidyalaya (NIT Silchar), Jawahar Navodaya Vidyalaya (Pailapool), and other local schools explored the observatory and engaged with astronomy experts.

ii) International and Academic Collaboration (18th November 2024):

A delegation comprising faculty members from Pittsburgh University (USA), ADA University (Azerbaijan), NIT Srinagar, and NIT Silchar visited the Department of Physics. The group exchanged ideas with faculty, research scholars, and M.Sc. students.

iii) Engaging Young Learners (December 2024)

ICARD continued its mission to ignite scientific curiosity among young minds with the following programs:

- **December 06, 2024**: Elementary school students from Cachar District, Assam under the Sarba Shiksha Abhiyan, visited the Department of Physics. They explored the laboratory facilities and the observatory, gaining exposure to astronomy and physics.
- **December 20, 2024**: A night sky observation camp was organized for Assam University students and faculty, fostering a sense of wonder and camaraderie under the stars.
- **December 23, 2024**: Higher Secondary students from Narsingh H.S. School, Silchar visited the campus for an interactive session with ICARD scholars.
- **December 24, 2024**: Students from Banshkandi M.E. School, Cachar, Assam engaged with ICARD researchers, learning about the cosmos through lectures and telescope observations.

iv) Yuva Sangam Phase V (January 11, 2025)

Assam University proudly hosted students from Chhattisgarh as part of the Yuva Sangam Phase V program. The visitors explored the Aryabhatta Astronomical Observatory, interacting with faculty and scholars. This exchange provided a unique platform for cultural and scientific dialogue, enriching their understanding of astronomy and astrophysics.

v) Community Outreach (January 2025)

ICARD extended its efforts to local schools and communities:

- **January 18, 2025**: Students from Ramani Mohan High School, Berenga, Silchar visited ICARD, participating in educational activities at the observatory.
- **January 31, 2025**: Students and teachers from Bimola Tribal M.E. School, Alambag toured the Astronomical Observatory and the Science Museum at the Department of Physics, deepening their appreciation for science.

vi) National Science Day Celebration (28th February 2025):

To commemorate National Science Day, ICARD organized a Night Sky Observation event at Cachar College, Silchar. This public outreach program brought together students, educators, and astronomy enthusiasts to celebrate science and explore the night sky through telescopes, reinforcing ICARD's commitment to community engagement.

Department of Physics, Tezpur University, Tezpur

Coordinator:
Dr. Rupjyoti Gogoi

Areas of research

Interstellar Dust, Active Galactic Nuclei, Galaxies, X-ray Astronomy, Solar Astronomy.

Research work done in ICARD

Faculty members and PhD students of Department of Physics, Tezpur University have been involved in collaborative research work with IUCAA faculty members since long time. Since the inception of ICARD at Tezpur University, six students, Dr Gautam Saikia, Dr Aishawnnya Sharma, Dr. Pranjupriya Goswami, Dr. Rukaiya Khatoon, Dr Kabita Deka and Dr Anshuman Borgohain have received their PhD degrees. All of them worked in close collaboration with IUCAA faculty members Prof. Ranjan Gupta, Prof. Ranjeev Misra, Prof. Kanak Saha and Prof. Durgesh Tripathi.

There are ongoing research work on Active Galactic Nuclei, X-ray Astronomy and Solar Astronomy in active collaboration with IUCAA faculty members. Group members of Prof. Gazi Ameen Ahmed and Dr Rupjyoti Gogoi are involved in these collaborative research works. The students presently involved are Janmejoy Sarkar and Hritwik Bora. Dr Biplob Sarkar from Department of Applied Sciences and his PhD students Sree Bhattacherjee and Arbind Pradhan are also working in collaboration with Prof. Ranjeev Misra in the field of X-ray Astronomy.

Workshops/schools organised by ICARD

ICARD, Tezpur University organised "North-East Meet of Astronomers (NEMA) – X" during October 23-25, 2024. NEMA is an annual gathering of astronomers in North East India, which was initiated in 2015. Over the years, NEMA has expanded significantly, with different institutions across the region hosting the event, reflecting the dynamic growth of the astronomical community in North East India.

Publications using ICARD facilities

1. Human resource development in astronomy: An Indian perspective, Journal of Astrophysics and Astronomy, Volume 46, article number 18, (2025).

2. The Solar Ultraviolet Imaging Telescope on Board Aditya-L1", Solar Physics, Volume 300, article number 30, (2025).

3. Science filter characterization of the Solar Ultraviolet Imaging Telescope (SUIT) on board Aditya-L1., Experimental Astronomy, Volume 59, article number 3, (2025).

Outreach program (including public lectures / sky watch) organised by ICARD

An astronomy talks and interaction session by Prof. Michael Rutkowski from Minnesota State University was held on September 23, 2024 to familiarize UG and PG students of Department of Physics, Tezpur University with the ongoing research activities in the field of Astronomy and Astrophysics.

Honours/Distinctions/Awards, etc., received by persons connected with ICARD

Dr Anshuman Borgohain received State Science award "**Young Scientist/Innovator Award**" from the Science Technology and Climate Change Department, Government of Assam for the year 2025. Dr Anshuman was registered with Dr Rupjyoti Gogoi of Tezpur University and worked with Prof. Kanak Saha from IUCAA for his PhD thesis.

Department of Physics and Electronics, Christ (Deemed to be University), Bengaluru

Coordinator:
Prof. Shivappa B. Gudennavar

Technical workshops organised by ICARD:

- Two-day workshop on ***Beginner Astronomy and Telescope Making*** held at St. Claret PU College, Bengaluru, in association with ICARD, Department of Physics and Electronics, CHRIST (Deemed to be University), Bengaluru, during **January 11-12, 2025.**
- A two-day beginner Astronomy Workshop was held at the Department of Physics and Electronics, CHRIST (Deemed to be University) for the students at Christ Junior College, Bengaluru, on March 6-7, 2025.

Technical seminars organised by ICARD:

The Department organised weekly Guest Lectures and Colloquia on recent developments in Astronomy and Astrophysics during the period of the report:

- Seminar on 'Transitional millisecond pulsar PSR J1023+0038: an emitter of continuous gravitational waves' by Prof. Sudip Bhattacharyya, Tata Institute of Fundamental Research, Mumbai, on September 26, 2024.
- Arranged a visit of fifteen selected students to IUCAA, Pune during March 9-13, 2025.

Public Outreach event arranged by ICARD:

A workshop on ***Beginner Astronomy and Telescope Making*** was held at St. Claret PU College, Bengaluru, in association with ICARD, Department of Physics and Electronics, CHRIST (Deemed to be University), Bengaluru, during **January 11-12, 2025.**

Proposed Activities for the ICARD:

- "A workshop on Beginner Astronomy and Telescope Building" proposed to be held in north Karnataka (Proposal in pipeline).
- One-day Astronomy Outreach Programme is planned to be held at Government High School, Begur, Bengaluru (Proposal in pipeline).
- National and International conferences on thrust areas of astronomy and astrophysics.
- Hands-on training and experimental workshops for students and teachers in astronomy.
- Summer research internships for undergraduate and postgraduate students.

School of Studies in Physics and Astrophysics, Pandit Ravishankar Shukla University, Raipur

Coordinator:
N. K. Chakradhari

Areas of research

Supernovae and X-ray Binaries

Research work

Spectral and timing study of X-ray binaries was conducted by Pravat Dangal (Thesis awarded) under the supervision of N.K. Chakradhari, in collaboration with Ranjeev Mishra (IUCAA, Pune). Two new PhD scholars have joined to work in this field in collaboration with IUCAA, Pune.

UV-optical photometric and spectroscopic studies of supernovae were carried out by Ms Shritika Tiwari (Thesis awarded). Kripa Ram Sahu and Mulchand Kurre are conducting ongoing thesis work in this field under the supervision of N.K. Chakradhari, in collaboration with G.C. Anupama and D.K. Sahu (IIA, Bengaluru).

Recent results from supernova studies were presented at ASI 2025, NIT Rourkela. A research paper on X-ray binary studies has been submitted to JHEAP, and two other manuscripts are in preparation for submission to peer-reviewed journals.

List of publications

1. Weak secondary cyclotron line in eclipsing High Mass X-ray Binary Cen X-3, Pravat Dangal, Ranjeev Misra, N. K. Chakradhari, Yashpal Bhulla, 2024, MNRAS, 527, 6981.
2. Search for merger ejecta emission from late time radio observations of short GRBs using GMRT, Ankur Ghosh, C. S. Vaishnava, L. Resmi, Kuntal Misra, K. G. Arun, Amitesh Omar, N. K Chakradhari., 2024, MNRAS, 527, 8068.
3. Photometric and spectroscopic studies of Type Ia supernova SN 2011ae, K. R. Sahu, N. K. Chakradhari, Mulchand Kurre, Shrutika Tiwari, G. C. Anupama, D. K. Sahu, presented at 43rd annual Meeting of the Astronomical Society of

India (ASI 2025), hosted by NIT, Rourkela, during 15-19 Feb 2025.

Outreach programmes

Regular sky-watching programs, telescope demonstrations, and planetarium shows were organized to observe various astronomical events. These events were conducted both at ICARD and external locations using ICARD facilities. Some of the outreach programs include: (1) NIT Raipur on 28-03-2025, (2) Govt. Science College Raipur on 05 March 2025 (3) Govt. P.G. College Arang on 10 Feb 2025 (4) RAF Farm Gariaband on 11 January 2025 (5) Swami Atmanand Govt. English Medium School of Excellence (SAGES), Nayabazar, Rajhara on 7 Dec 2024.

N.K. Chakradhari participated in a panel discussion on "India's Space Saga" on the eve of National Space Day 2024 (August 22, 2024). The program was broadcast live by Doordarshan Raipur and was also screened in several government schools as part of the National Space Day celebrations.

Centre for Theoretical Physics, Jamia Millia Islamia (A Central University), New Delhi

Coordinator:
Prof. Sushant Ghosh

Areas of research

Cosmology, Black Hole Shadow and EHT Results, Gravitational Lensing by Black Holes, Black Hole Thermodynamics, Quasi-normal Modes (QNMs)

Research work done in ICARD

The group actively investigates cosmological tensions, including the Hubble Tension, S_8 tension, and anomalies in JWST observations of massive galaxies at high redshifts, challenging the standard ΛCDM model. We proposed an AdS-like model in the Dark Energy sector as a potential resolution to the Hubble tension. This model was further examined in the context of JWST high-redshift galaxy abundances and future SKA-Mid 21cm signals. Additionally, we explored GRB observations' role in addressing cosmological tensions arising from low-redshift and CMB data.

Progress in black hole physics has been driven by modified gravity, quantum corrections, and string theory, alongside observational constraints from the Event Horizon Telescope (EHT). This report synthesizes key findings from 23 papers (2024–2025) on black hole shadows, gravitational lensing, plasma effects, and thermodynamics.

Studies explored how surrounding matter influences black hole shadows and lensing. We examined Sen black holes in plasma, finding dispersive effects on shadow morphology. We showed that GUP-modified Schwarzschild black holes alter lensing observables, relevant for quantum gravity.

We analysed quantum-corrected black holes, identifying lensing deviations from GR predictions. We extended this to rotating cases, using EHT data for constraints. We also studied strong lensing in string theory, comparing with EHT results.

We examined rotating black holes in bumblebee gravity, a Lorentz-violating extension of GR, and constrained its parameters with EHT data. We studied EGB gravity coupled to a bumblebee field, showing how these models differ from GR black holes.

We explored rotating 4D-EGB black holes in dark matter environments, identifying measurable effects on shadow size and lensing. We found that dark energy influences photon orbits and thermodynamic phase transitions, linking cosmic acceleration to black hole thermodynamics.

Black hole thermodynamics in modified gravity frameworks was a key focus. Studies on regular-AdS and Bardeen-Letelier black revealed critical behavior analogous to van der Waals fluids. Also, examined Kiselev-AdS black holes, showing modified gravity's impact on thermodynamic stability.

We have analysed particle acceleration near rotating charged black holes in 4D-EGB gravity, identifying enhanced energy extraction mechanisms relevant for high-energy astrophysics.

Studies in 2024-25 by black hole group highlight significant progress in testing modified gravity, quantum corrections, and string theory through black hole observations:

Plasma and quantum effects impact black hole shadows and lensing.

EHT data constrain parameters in bumblebee gravity, EGB gravity, and string-inspired models.

Dark matter and dark energy affect black hole thermodynamics and observational features.

Thermodynamic phase transitions in modified gravity black holes exhibit rich critical behaviour.

The work resulted in 23 publications in high impact journal reported in the annual IUCAA report.

Workshops/schools organised by ICARD

a. The Centre for Theoretical Physics (CTP), Jamia Millia Islamia (JMI), in collaboration with the Inter-University Centre for Astronomy and Astrophysics

(IUCAA), hosted a prestigious international conference titled "Tensions and Anomalies on the Sky: Quest for New Physics at Cosmological Scales" between March 6-8, 2025.

b. National Science Day February 28, 2025 – 1. Poster Display with Explanation by PhD scholars 2. Talk by Prof Anjan Sen

c. National Space Day on 23rd August 1. Quiz Competition 2. Special Talk – Dr Suprit Singh – IIT Delhi.

1. **List of publications by using ICARD facilities**

   The list of publications is included under 'Publications by Visiting Associates', hence, not provided here.

2. **Any outreach programmes, including public lectures/sky watch arranged by ICARD, etc.**

   a. The National Science Day February 28, 2025 Poster Display with Explanation by Ph.D. scholars, February 28, 2025.
   b. The National Space Day on August 23, 2025.
   c. Dr. B.C. Paul, Professor, NBU, Siliguri under the ICARD program. Dr. Paul visited during December 18 - 24, 2024.

3. **Any honors/distinctions/awards, etc., received by persons connected with ICARD**

   Our article by Sushant Ghosh, Rahul Kumar and Shafqat Ul Islam titled "Parameters estimation and strong gravitational lensing of non-singular Kerr-Sen black holes", published in the Journal of Cosmology and Astroparticle Physics has been honoured with the IOP Publishing Top Cited Paper Award - 2024 for India in the Astronomy and Astrophysics category!

Sri Venkateswara College (South Campus), University of Delhi, New Delhi

Coordinator:
Dr. Main Pal

Research Area:

Multiwavelength studies of accreting sources such as active galactic nuclei and X-ray binaries: Timing behaviour and Spectral variations of complex X-ray corona, accretion disc, and surrounding atmosphere.

Brief report on research since the conception of ICARD, SVC, DU: I have been involving in multiple projects and work is going on numerous topics. We published recently few following publications on AGNs.

Publications:

1. **Late-time radio brightening and emergence of a radio jet in the changing-look AGN 1ES 1927+654.** *Astrophys. J. Lett.* 979 (2025) 1, L2. https://arxiv.org/abs/2406.18061 DOI: 10.3847/2041-8213/ad8651

2. **Multiwavelength Observations of a Jet Launch in Real Time from the Post-changing-look Active Galaxy 1ES 1927+65.** *Astrophys.J.* 981 (2025) 2, 125. https://arxiv.org/abs/2501.02340 DOI: 10.3847/1538-4357/adaea0

Activities at ICARD, SVC

We conducted following two public lectures during the National Science Day 2025:

1. The Raychaudhury Equation: An Introduction by Prof. Hemwati Nandan, HNBGU, Sri Nagar, U.K. on 27/02/2025

2. Thermodynamics of convection by Prof. T. R. Seshadri, Department of Physics and Astrophysics, University of Delhi on 28/02/2025

School of Arts and Sciences, Ahmedabad University, Ahmedabad

Coordinator:
Dr Samyaday Choudhury

Areas of research

Observational Studies of Stellar Populations and Star Clusters, Evolution of Dwarf Galaxies, Multiwavelength Astronomy and Big Data Analysis.

The School of Arts and Sciences, Ahmedabad University, began to function as a host of ICARD from November 2024. The group carries out research in Astronomy and Astrophysics-related activities in collaboration with the members of the International Centre for Space and Cosmology (ICSC, Ahmedabad University), namely, Prof. Pankaj Joshi (Gravitation), Prof. Gaurav Goswami and Prof. Raghavan Rangarajan (both in Cosmology).

Activity

ICARD at Ahmedabad University organised the Ahmedabad Astrophysics Meet-I on February 22, 2025. The meeting featured ten talks by researchers from Ahmedabad University, Physical Research Laboratory, IIT Gandhinagar, Institute of Plasma Research, and Space Applications Centre (ISRO). The meeting covered diverse areas of Astrophysics, namely, Theoretical Astrophysics; Observational studies of AGNs; Star-formation; Observational studies of dwarf galaxies; Dark-matter and Astroparticle Physics; Naked singularities and Astrophysical Data Analysis.

There were poster presentations by the students at Ahmedabad University and discussions on key questions pertinent to modern Astrophysics, with a focus on addressing these challenges by strengthening inter-institutional collaborations in the neighbourhood. Additionally, the meeting engaged with student attendees from the neighbourhood, such as St. Xavier's College, PDEU, MG Science College and the Charotar University of Science and Technology.

Department of Physics and Astronomical Sciences, Central University of Himachal Pradesh (CUHP), Dharamshala, Himachal Pradesh

Coordinator:
Prof. Hum Chand

Research Area

Astrophysics, Cosmology, Neutrino physics, Particle Physics and Gravitational Physics

Research Work Done in ICARD

The astronomy group at CUHP primarily focuses on extragalactic astronomy and observational cosmology, addressing a range of significant topics. One of the key research areas is the study of quasar absorption lines, where the team investigates the evolution of high-redshift proto-galaxies. Another major focus is

cosmology using the Lyman-alpha forest technique to understand the large-scale structure of the universe. Additionally, the research on Active Galactic Nuclei (AGN) includes studies on AGN variability, black hole mass estimations, and multi-wavelength analyses of AGNs.

Recent investigations undertaken by the astronomy group encompass diverse and pioneering topics. One of the major studies focused on weak emission-line quasars (WLQs), where the team examined the optical variability of 76 radio-quiet WLQs and compared them with a control sample of 603 normal radio-quiet quasars. Using data from the Zwicky Transient Facility and the Catalina Real-Time Transient Survey, the group found that WLQs exhibit systematically milder variability compared to their normal counterparts. This observation suggests that the clumpy nature of the torus material feeding the central engine may be responsible for the observed differences, thereby providing insights into the enigmatic nature of WLQs.

Another significant study involved star formation in damped Lyman-alpha absorbers (DLAs), where the group examined 1,716 DLAs from the Sloan Digital Sky Survey. The analysis revealed Lyα emission with a luminosity of 8.95×10^{40} erg s^{-1}, suggesting that DLAs form stars at an average rate of approximately 0.54 $M_\odot$ per year. These findings not only reinforce the association between DLAs and lower-mass Lyman-α emitting galaxies but also underscore the role of DLAs as crucial reservoirs of neutral hydrogen during cosmic noon.

The department also conducted a rare and unprecedented pilot project to monitor the intra-night optical variability of a quasar undergoing a transition from a radio-quiet to a radio-loud state. The targeted quasar, J0950+5128, which had recently exhibited jet activity, was observed across six high-cadence R-band observation sessions. Despite the extensive monitoring, the team detected no significant blazar-like variability, apart from a brief 0.15-magnitude spike. This investigation highlights the necessity of continuous monitoring to capture transient jet dynamics and their optical manifestations.

Apart from research in observational astronomy, the group also made substantial contributions to astronomy education by conducting a comprehensive nation-wide survey (with our contribution on Himachal Pradesh) to assess the status of astronomy education among secondary school students across India. On a national scale, this survey, administered in 10 languages and involving more than 2,000 students from diverse socioeconomic backgrounds, revealed considerable gaps in fundamental astronomical knowledge and limited access to educational resources. Despite these challenges, the survey identified a strong enthusiasm for astronomy among students, indicating a latent potential that could be harnessed through curriculum enhancement and teacher training initiatives.

Neutrino Physics Research at CUHP: The neutrino physics group at CUHP is committed to exploring the fundamental connections between neutrino mass, dark matter models, lepton flavor structure, and leptogenesis scenarios. A major focus of their research is to understand the origin of neutrino mass, which remains an open problem within the Standard Model. The group investigates mechanisms such as the seesaw model and radiative mass generation to provide viable theoretical explanations consistent with experimental data. An essential aspect of their work involves examining the interplay between neutrino mass and dark matter, constructing minimal extensions of the Standard Model that accommodate stable dark matter candidates while explaining neutrino oscillation data and cosmological observations.

Furthermore, the group investigates the role of lepton flavor symmetries and their breaking patterns in shaping the observed hierarchy of charged lepton and neutrino masses. By employing group theoretical methods, they construct predictive models that could be tested in future experiments. The study of leptogenesis as a mechanism for generating the baryon asymmetry of the universe is another crucial aspect of their work, linking neutrino properties to the cosmic matter-antimatter imbalance. The group's approach is deeply rooted in phenomenology, combining analytical model-building techniques with numerical simulations to explore viable parameter spaces consistent with current neutrino oscillation data, cosmological observations, and experimental constraints.

Additionally, the group actively searches for potential signals of new physics in upcoming experiments and future colliders, identifying novel signatures that could differentiate between various Beyond Standard Model (BSM) scenarios. By bridging the study of neutrino physics with broader themes in particle physics and cosmology, the research group aims to construct a unified understanding of the fundamental forces and particles that govern the universe. Their efforts contribute significantly to advancing our knowledge of neutrino properties, lepton flavor evolution, and the longstanding mystery of dark matter, paving the way for a deeper comprehension of the fundamental laws of nature.

Our department, which began hosting ICARD in 2022, has made substantial progress in enhancing its astrophysics and astronomy program by introducing astronomy courses at undergraduate, postgraduate, specialization, and PhD levels. Prof. Hum Chand coordinates ICARD with the support of three other IUCAA associates: Prof. Bhag Chand, Dr. Surinder Verma, and Dr. Ayan Chatterjee. Alongside these experts, other faculty members and a dedicated group of research scholars contribute to the department's efforts. As a result of these combined initiatives, we have achieved remarkable student enrollment, including about 30–40 students in general astronomy courses at the undergraduate and postgraduate levels, 5–6 students specializing in astronomy, 7 students enrolled in the PhD program in Astronomy, and about 9 students involved in particle and gravitational research.

Workshops/Schools Organized by ICARD

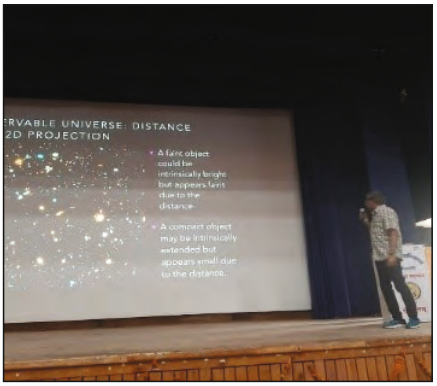
(I) The ICARD Center of the Department of Physics & Astronomical Science (DPAS), Central University of Himachal Pradesh (CUHP), in collaboration with IUCAA and the University of Kashmir, organized the **Himalayan Meet of Astronomers (HMA)** from September 14 - 15, 2024 at CUHP, Dharamshala.

(ii) Advancements in AGN, Galaxy Cluster and IGM Research' 2024 (March 29 - 31, 2024) CUHP Dharamshala

Photo: The participants of conference on "Advancements in AGN, Galaxy Cluster and IGM Research"

Outreach programs:

During the workshop, participants also seized the opportunity to engage in outreach activities in the region. Notably, Prof. R. Srianand delivered a science popularization lecture at the auditorium of the Govt. Degree College Dharamshala. His talk, titled "Tracing the Evolution of the Universe Using Powerful Astronomical Telescopes," attracted an audience of about three hundred students from various schools in the Dharamshala area.



List of publications by using ICARD facilities

Weak emission-line quasars: a new clue from their optical variability,

a. Kumar, Ritish; Krishna, Gopal-; Chand, Hum, Negi, Vibhore, 2025, MNRAS, 538L,83K.

b. Star formation in neutral hydrogen gas reservoirs at cosmic noon, Dharmender; Joshi, Ravi; Fumagalli, Michele; Noterdaeme, Pasquier; Chand, Hum; Ho, Luis C, 2024, A&A, .692L, 7D.

c. Intranight optical monitoring of the rare quasar J0950+5128, the brightest known candidate for transition from radio-quiet to radio-loud state, Chand, Krishan; Gopal-Krishna; Chand, Hum,

PASA, 2024arXiv241108106C.

d. Status of Astronomy Education in India: A Baseline Survey, Maji, Moupiya et al.(including Chand, H.) Physics Education (in press), arXiv:2406.12308.

Outreach programmes, including public lectures/sky watch, arranged by ICARD, etc.

Our Master's and research degree students also take part in outreach activities under the department club namely Chandra - STAR (Science Technology & Astronomy Realization) club (e.g https://chandrastarclub.github.io/). The activities include arranging lectures (online/offline) and sky show for general public and school/college students. Few recent such activities are as listed below.

1] Talk by Hum Chand "Touching Lives while Touching the Moon: India's Space programme and our connection with the cosmos" dated 07 August 2024 at ICARD CUHP Dharamshala.

2] Documentaries on eminent scientists like Vikram Sarabhai and others, followed by interactive discussions to engage students and deepen their understanding at ICARD CUHP Dharamshala

3] A popular talk by Hum Chand on "astronomy and space sciences." for School students Shahpur, at Shahpur Campus.

4] A popular talk by Prof. Bhag Chand Chauhan on "Ancient Astronomy and Space Science in India" at ICARD CUHP August 14 2024.

5] Declemation, Quiz competition covering astronomy, astrophysics, and space exploration history, 23 August 2024.

6] Public talk "Tracing the Evolution of the Universe Using Powerful Astronomical Telescopes," by Prof. R. Srianand, to school and college students on 28th March 2024 at ICARD Dharamshala

7] Public talk, "Aditya Calling Aditya," by Prof. Durgesh Tripathi", to school and college students on 13th September 2024 at ICARD Dharamshala

Department of Physics, University of Kashmir, Srinagar, Jammu and Kashmir ICARD

Coordinator:
Professor Manzoor A. Malik

Areas of research

Theoretical Astrophysics, Cosmology, Galaxy Clusters, Radio and X-ray Astronomy, Blazers

Research during the period

There are two ongoing research projects in the field of Astronomy and Astrophysics; One titled "Radio and X-ray studies of non-thermal processes in galaxy clusters and galaxy groups" (PI: Manzoor Malik) and another titled "Unveiling the High energy emission properties of Blazars using AstroSat Observations" (PI: Naseer Iqbal). Besides, 6 students are pursuing their Ph. D. in different areas of A&A in our department. Faculty members in other universities and colleges (some of whom are also IUCAA associates) are also working and publishing in diverse areas of Astronomy and Astrophysics.

Selected publications during the period are listed below:

1. Study of multi-wavelength variability, emission mechanism and quasi-periodic oscillation for transition blazar S5 1803+ 784 by J Tantry et al, Journal of High Energy Astrophysics, 100372, 2025

2. Time resolved spectroscopy of a GRS 1915 + 105 flare during its unusual low state using AstroSat by Sajad Boked et al MNRAS 528(4):7016-7026, 2024

3. Insights into the Long-term Flaring Events of Blazar PKS 0805-07: A Multiwavelength Analysis Over the Period of 2009–2023 by S Akbar et al, The Astrophysical Journal 977 (1), 111, 2024

4. Probing broadband spectral energy distribution and variability of Mrk 501 in the low flux state by J Tantry, Z Shah, R Misra, N Iqbal, S Akbar, Journal of High Energy Astrophysics 44, 393-409, 2025

5. Quantum Theory of 3+ 1 Gravity and Dark Matter: A New Formulation of the Gupta-Feynman based Quantum Field Theory of 3+ 1 Einstein Gravity by H Mir et al, Journal of Holography Applications in Physics 4 (4), 21-58, 2024.

6. Revisiting the Schwarzschild black hole solution: A distributional approach by Q Gani et al, Physics of the Dark Universe 46, 101604, 2024.

Meetings/Workshops:

A three-day **Workshop on High Performance Computing** was organized during May 22-24, 2024 at University of Kashmir. Around 60 participants that included M Sc (Science) students, Ph. D.

students and faculty actively attended the workshop. The workshop was coordinated by Sanjit Mitra (IUCAA) and Manzoor A. Malik (University of Kashmir).

Seminar:

Radio Astronomy - Playground for Engineers and Physicists alike! By Dr. Nivedita Mahesh, California Institute of Technology, July 22, 2024.

Department of Mathematics and Computing, Indian Institute of Technology (ISM), Dhanbad, Jharkhand

Coordinator:
Prof. Badam Singh Kushvah

Outreach activities organised at IIT(ISM) Dhanbad

- **Close Approach of Jupiter and Mars:** Wednesday, 14th August 2024 at 20:23 IST
- **Full Moon Day Observation:** Monday, 19th August 2024 at 23:55 IST
- **Open Talk on India and Space Astronomy:** Tuesday, 20th August 2024 at 18:30 IST
- **School-level Interaction on Telescopes:** Wednesday, 21st August 2024 at 10:00 IST

National Space Day Celebration 2024: Events organized during August 14-21, 2024

1. **Sky Watch on Close Approach of Jupiter and Mars, Date: Wednesday, 14th August 2024**

   An introductory session was arranged in the New Academic Complex Auditorium, where Prof. Badam Singh Kushvah, M&C delivered lecture on "Introduction to the Planets and Their Significance in the Solar System". Before the lecture, Prof. Ajit Kumar highlighted the series of events to be organized by the institute for celebration of the National Space Day. More than 200 participants observed the sky and enjoyed a lot by looking the various objects in the sky using 25mm and 10mm eye pieces.

2. **Full Moon Night Sky Observation, Date Monday, 19th August 2024**

   The full moon sky watch observation was started at 7:00PM and ended around 11:55PM. More than 200 participants attended the full moon sky watch event.

3. **Open Talk on India and Space Astronomy, Date Tuesday, 20th August 2024**

   The open talk was delivered by Mr. Samir Dhurde, In-charge SciPop, IUCAA, Pune, in the New Academic Complex Auditorium at 6:30PM. More than 150 participants attended the session.

4. **School-level Interaction on Telescopes, Date & Time: Wednesday, 21st August 2024 at 10:30AM**

   A special session for school students was arranged in the Golden Jubilee Lecture Theatre (GJLT) to demonstrate the different types of telescopes and their uses. Mr. Samir Dhurde, In-charge SciPop, IUCAA, Pune has discussed about the various components of a telescope and made a telescope with locally available thing like plastic pipe, tapes, glass holder, photography tripod with convex lenses, and eyepieces, the students have got hands-on experience with telescopes and learned how to make and operate them. More than 100 students attended the session.

ICARD- Manipal Centre for Natural Sciences (MCNS), Centre of Excellence, Manipal Academy of Higher Education (MAHE)

Coordinator:
Dr Debbijoy Bhattacharya

Area of research:

MCNS researchers are involved in theoretical studies, multi-wavelength observation and associated modelling in various fields of astrophysics, which include cosmic inflation, cosmic microwave background anisotropy, dark matter, primordial black holes, High Energy Astrophysics, transient phenomena and exotic objects such as X-ray binaries, AGN, supernova and gamma-ray burst, black hole physics and astrophysical jets, solar physics and space instrumentation.

Brief report about the research work done:

The astrophysics and cosmology group at MCNS is actively involved in both theoretical and observational research. Researchers from this group extensively use observational data from various national and international observatories (e.g., JCBT-Kavalur, HCT-Hanle, ASTROSAT, Fermi, Swift, Planck, SDSS, etc). MAHE became a member of the SKA-India Consortium in November 2023. Faculty from MCNS are actively involved in the development and characterisation of SUIT payload onboard India's space-based Solar observatory ADITYA-L1.

During the last year, **23 papers** were published by the astrophysics group at MCNS. The details of the research publications by MCNS researchers are given in **Annexure I**. Also, **2 projects** received external funding during this period (details in **Annexure II**). The total number of research grants (sanctioned/ongoing) is **5** during the last year.

1. List of Workshop/schools organised by ICARD:

a. ASTRO-CAMP: A Three-Day workshop

"Astro-Camp: A Three-Day Workshop" was held at Manipal Centre for Natural Sciences, Manipal Academy of Higher Education (MAHE), Manipal, from April 16-18, 2024, jointly organised and funded by MAHE and IUCAA.

b. National Space Day celebration

National Space Day was celebrated to commemorate the successful landing of Chandrayaan-3 on the Moon. A total of 13 schools participated in the competition, showcasing their knowledge of space science.

c. A one-day workshop on 'Introduction to Astrophysics: New Views of the Universe" was organized.

d. Manipal Astrostatistics School (MAS)

MAS was organised in collaboration with Penn State University, IUCAA, Harvard Smithsonian, SINP, and BARC. A total of 170 applications were received from various parts of India as well as a few from outside India such as South Africa, France, and the UK. The total number of participants, including MAHE and nearby regions is close to 100.

e. National Science Day celebration

The National Science Day was celebrated on 28th of February 2025. Students of levels 8 and 9 from 10 schools participated in the event along with a teacher representative from each school. Around 40 participants attend the event.

Talks organised

1. **Seminar on Lunar Exploration: Why & How? by** Dr. Shyama Narendranath, U R Rao Satellite Centre, Indian Space Research Organisation (ISRO) **Date**: 02 May 2024.
2. **Unveiling Diversity in GRB Progenitors: A Data-Driven Approach using Machine Learning by** Dr. Dimple, Postdoctoral Fellow, Chennai Mathematical Institute (CMI), India **Date**: 19 June 2024
3. **Exploring the Solar Atmosphere: A Theoretical and Observational Perspective by** Dr. Megha Anand, Postdoctoral Fellow, MCNS, MAHE **Date**: 21 August 2024
4. **Inflationary Models in Perturbative Large Volume Scenario by** Dr. Dibya Chakraborty, Centre for Strings, Gravitation and Cosmology, IIT Madras **Date**: 11 September 2024
5. **Confronting the Cosmological Principle Using Radio Galaxies and Quasars** by Prof. Geraint Lewis, Professor of Astrophysics, University of Sydney **Date**: 09 October 2024
6. **Formation of Sub-Solar-Mass Black Holes and Naked Singularities from Transmutation of White Dwarfs by** Dr. Chandrachur Chakraborty, Assistant Professor, MCNS, MAHE **Date**: 23 October 2024
7. **Photon Ring Polarimetry and Next-Generation Black Hole Imaging by** Mr. Aditya Tamar, Masters Student, National Institute of Technology Karnataka (Surathkal) **Date**: 30 October 2024
8. **Exploring the Neutrino Flavor Mixing Through the Window of Tribimaximal Mixing by** Dr. Sumit Kumar, Assistant Professor, MCNS, MAHE **Date**: 13 November 2024
9. **Recent Advancements in the Study of Nuclear Transients in Distant Galaxies by** Dr. Rupak Roy, Assistant Professor, MCNS, MAHE **Date**: 27 November 2024
10. **Unveiling the Invisible: Dark Matter and Dark Energy in Cosmology and Fundamental Physics by** Dr. P Poulose, Professor, Dept. of Physics, IIT Guwahati **Date**: 09 December 2024
11. **Outflows from Galaxies by** Dr. Biman Nath, Professor, Raman Research Institute, Bangalore **Date**: 18 December 2024
12. **A New Mass Estimate Method with Hydrodynamical Atmospheres for Very Massive WNh Stars by** Dr. Gautham Sabhahit, Armagh Observatory, UK **Date**: 15 January 2025
13. **Symmetries in Physics by** Dr. S.G. Rajeev, Professor of Physics and Emeritus Professor of Mathematics, University of Rochester, NY **Date**: 12 February 2025
14. **Black Holes and Quantum Gravity by** Dr. Chethan Krishnan, Professor, Centre for High Energy Physics (CHEP), IISc Bengaluru **Date**: 13 February 2025
15. **Extinction Curves: Diffuse to Dense Sightlines by** Dr. Shalima Puthiyaveettil, Assistant Professor, MCNS, MAHE **Date**: 26 February 2025
16. **The James Webb Telescope and Observations of the Early Universe by** Prof. Ajit Kembhavi, Emeritus Professor, Inter-University Centre for Astronomy and Astrophysics (IUCAA) **Date**: 05 March 2025
17. **From Superstring Theory to Gravitational Waves by Presenter**: Dr. Kazuyuki Furuuchi, Associate Professor, MCNS, MAHE **Date**: 12 March 2025

Outreach program (including public lectures / sky watch) organised by ICARD

MCNS organised sixteen seminars/colloquiums/popular talks from 01 April 2024 to 31 March 2025 on the various topics of Astrophysics.

Honors/distinctions/awards, etc., received by persons connected with ICARD

1. **P. Sreekumar,** Chair of the Venus Orbiter Mission - Standing Committee.
2. **P. Sreekumar,** invited as a member of the Scientific Advisory Committee of IUCAA for a 5-year period, beginning April 2024.
3. **K. S. Sruthy**, PhD student, Awarded the prestigious DST-INSPIRE Fellowship by the Department of Science and Technology (DST), Gov. of India, November 2024.

Department of Information Technology, School of Information Science and Technology, Kannur University, Kerala

Coordinator:
Dr R. K. Sunil Kumar

Areas of Research

Astronomical time series analysis. Galaxy morphological classification gravitational wave detection, we integrate Topological Data Analysis (TDA) and Quantum Convolutional Neural Networks (QCNN) to improve accuracy in noisy environments. Quantum Fourier Transform (QFT), interactive apps integrated with Stellarium software and IoT-enabled astronomical toys and models.

Research Work carriedout in ICARD

ICISN 2025 -
Hanoi University of Industry, Vietnam

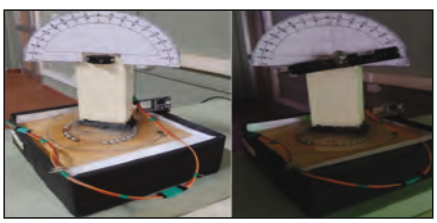
Quantum-Enhanced Signal Processing For Gravitational Wave Detection Using Quantum Fourier Transform

This study explores the application of the Quantum Fourier Transform (QFT) for analyzing gravitational wave signals, emphasizing its advantages over classical Fourier techniques. By leveraging quantum parallelism, the QFT offers superior resolution of low-frequency components, crucial for gravitational wave detection.
(**The work was presented at the fifth International Conference on Intelligent System & Network (ICISN-2025 -Springer – Scopus) at Hanoi University of Industry - Vietnam**)

Enhancing Astronomical Image Quality Using Physics-Informed Neural Networks and Blur-Specific Loss Functions

This study proposes a novel denoising approach using Physics-Informed Neural Networks (PINNs) to enhance astronomical images.
(This work was presented at the fifth International Conference on Intelligent System & Network (ICISN-2025 -Springer – Scopus) at Hanoi University of Industry - Vietnam)

STAR Buddy: An IoT-Based All-In-One Star-gazing System



Star Buddy Prototype

STAR Buddy enhances stargazing by integrating Stellarium's real-time data with an automated tracking system and user-friendly interface. It provides multilingual TTS, Wikipedia-based descriptions, realistic visuals, and a searchable database, making celestial navigation accessible to non-English speakers and the visually impaired. The system also supports educational engagement through an interactive chatbot and learning portal, bridging the gap between astronomical data and inclusive exploration.

National Science Day Celebration 2025

Organized by the Department of Information Technology, Kannur University as part of ICARD Centre activities

Introduction:

The Department of Information Technology, Kannur University, successfully organized a two-day workshop as part of the National Science Day Celebrations 2025, on February 28 and March 1, 2025.

List of Publications

1. E. Antony, R. K. Sunil Kumar, L.VL. Lajish, P. Sethumadhavan, , K. M. Muraleedharan, and M. C Jobi., "Enhancing astronomical image quality using physics-informed neural networks and blur-specific loss functions," in *Proc. 5th Int. Conf. Intelligent System & Network (ICISN 2025)*, Hanoi University of Industry, Vietnam, Springer, Scopus Indexed.
2. R. K. Sunil Kumar, E. Antony, S. V., N. S. Sreekanth, P. Sethumadhavan, V.L. Lajish, and M. C. Jobi, "Noise-resilient low-frequency signal analysis using quantum Fourier transform: A case study with gravitational waves," in *Proc. 5th Int. Conf. Intelligent System & Network (ICISN 2025)*, Hanoi University of Industry, Vietnam, Springer, Scopus Indexed.

Department of Physics, Bharata Mata College (Autonomous), Kochi Kerala

Coordinator:
Dr. Manesh Michael

Area of Research

Astronomy, Astrophysics, and Space Science

Brief report about the research work done in ICARD

Introductory Workshop on Astronomy and Astrophysics as part of ICARD centre inauguration of Bharata Mata College, Kochi The Introductory Workshop on Astronomy and Astrophysics was conducted at the AV Room of Bharata Mata College, Thrikkakara, as a part of ICARD Centre Inauguration sponsored by IUCAA, Pune. The workshop was conducted on February 1, 2025, offering a platform for in-depth discussions and knowledge sharing in the fields of solar physics and stellar spectroscopy.

The introductory workshop on astronomy and astrophysics was a resounding success and it provided a platform for experts and enthusiasts to come together and explore a diverse range of topics in the field of astronomy and astrophysics. The workshop was marked by informative and engaging sessions, stimulating discussions and valuable networking opportunities.

Department of Physics, Cochin University of Science and Technology, Cochin

Coordinator:
Dr. Charles Jose

Areas of research

- Cosmology - late acceleration of the Universe, Alternatives to dark matter and dark energy
- Structure formation in the Universe, Statistics of large-scale structure, Galaxy formation and evolution

Research work undertaken:

Research in the department spans neutrino physics, cosmology, and galaxy evolution. Studies on geometric phases in neutrino oscillations highlight their sensitivity to mass ordering and the Dirac CP phase, with notable symmetry and topological features in two-flavour models. In cosmology, a mixed dark matter model with viscous and inviscid components successfully explains late-time acceleration without a cosmological constant, while satisfying key physical conditions like the second law of thermodynamics.

In galaxy evolution, the environmental dependence of Lyman-break galaxy properties has been explored using large survey data, revealing strong correlations between UV magnitude or colour and environment. Another study models the redshift evolution of the radio luminosity function of star-forming galaxies, showing that small-scale magnetic fields dominate at high redshifts, with turbulence and outflows playing key roles.

Workshops/Schools organised by ICARD

During 2024-25, ICARD, CUSAT hosted two events in collaboration with ICARD, Newman College, Thodupuzha.

The Tenth Southern Regional Astronomy Meeting:

It was hosted from January 31 to February 2, 2025, at CUSAT which brought together over eighty researchers and faculty members who presented their work across diverse areas of astronomy and astrophysics and featured three plenary talks, multiple sessions chaired by senior scientists, a poster session, and a special memorial for Prof. V. C. Kuriakose. A discussion on career opportunities in astrophysics was also held to support and guide young researchers.

National Conference on Classical and Quantum Gravity:

The National Conference on Classical and Quantum Gravity was hosted from November 05 - 07, 2024, bringing together researchers and scholars from across India. The event, attended by fifty-five participants, offered valuable opportunities for early-career researchers to engage with experts and explore open problems in the field.

List of publications using ICARD facilities:

1. Charles Jose, Luke Chamandy, Anvar Shukurov, Kandaswamy Subramanian, Luiz Felippe S Rodrigues, Carlton M Baugh (2024), *Understanding the radio luminosity function of star-forming galaxies and its cosmological evolution*, MNRAS, 532, 2, 1504, DOI: https://doi.org/10.1093/mnras/stae1426
2. Emy Mons, Charles Jose (2025), *Probing Environmental Dependence of High-Redshift Galaxy Properties with the Marked Correlation Function*, The Open Journal of Astrophysics 8 [January], DOI: https:/⊗/⊗doi.org/⊗10.33232/⊗001c.128187
3. Manosh T. Manoharan, N. Shaji, Ramesh Babu Thayyullathil, Titus K. Mathew, *Off Diagonal Geometric Phases in Neutrino Mixing*, Springer Proc. Phys. 304, 635-636, DOI: https://doi.org/10.1007/978-981-97-0289-3_143
4. Manosh T. Manoharan & N. Shaji, 2025, *Reconciling fractional entropy and black hole entropy compositions*, 85, 373, DOI: https://doi.org/10.1140/epjc/s10052-025-14107-y
5. P.B. Krishna, Titus K. Mathew, *Emergence of cosmic space and the maximization of horizon entropy*, 44, 101451, DOI: https://doi.org/10.1016/j.dark.2024.101451
6. Vishnu A. Pai, Sarath N, Titus K. Mathew, 2025, *Bulk viscous late acceleration under near equilibrium conditions in f(R, T) gravity with mixed dark matter*, Class. Quant. Grav. 41, 8, 085002, DOI: https://doi.org/10.1088/1361-6382/ad3082

Department of Physics, 'Providence Women's College, Kozhikode, Kerala

Coordinator:
Dr. Jeena. K

Areas of research

1. Broadband spectral analysis and time variability studies of AGNs using data from different missions like AstroSat, Xmm-Newton, Nustar etc.
2. The solar origin of space weather and its impact on Earth's Magnetosphere-Ionsphere and an overall assessment of the solar wind pathways through which space weather impacts are mediated and thus to predict the space weather disturbances.
3. Strong gravitational lensing in different black hole space time**.**
4. X-ray variability studies of ultra-luminous X-ray sources.

Research work done in ICARD

One of the research interests include investigating the solar wind Magnetosphere-Ionosphere coupling, its solar cycle dependency, solar origin, evolution, and geo effectiveness of heliospheric large-scale structures specifically coronal mass ejections (CMEs) that are the major driver of space weather by using various in situ satellite data analysis techniques, empirical and data-driven semi-analytical modeling of large-scale heliospheric structures. We have analysed the effects of solar wind magnetosphere-ionosphere coupling and its efficiency during extreme minimum of the solar cycle23-24. We have researched the impacts of CME-CIR geomagnetic storms of 23-24 solar cycles.

Study of strong deflection gravitational lensing by Kazakov-Solodukhin black hole is also going on. We investigate the affine perturbation series of the deflection angle of a ray near the photon sphere of by Kazakov-Solodukhin black hole. The values of strong field parameters calculated and analysed its variation with deformation parameter. With the help of lens equation, the expression for angular position of innermost image, the angular separation of outermost image with the remaining images and the relative magnification derived. The numerical estimation of lensing observable for different super massive black holes are performed.

Active galactic nuclei refer to the compact region at the centre of some galaxies with luminosity much higher than normal. They are observed to emit in almost all the wavelengths of the electromagnetic spectrum. We study the spectral and variability properties of AGNs in X-ray energies. The first project studied to understand the soft excess component in a Seyfert galaxy by analysis its time variability properties. In the second work we study the long term spectral variations of a Seyfert galaxy, using multiple mission data.

Research work also focuses on identification of bright Ultra Luminous X-Ray Sources in nearby Galaxies and their Multiwavelength studies using archival data, checking the variability in different wavelength bands and the identification of ulx nebulae.

List of workshops/schools organised by ICARD

1. One-day workshop on **'Radio Astronomy Fundamentals'** was organized on 18th October 2024. The resource persons were Dr. Joe Jacob, Retd. H.O.D, Department of Physics, Newman College, Thodupuzha and Dr. Mathew George, Assistant Professor Department of Physics, SH College, Thevara.
2. One-day Seminar on '**Radio Astronomy'** was organized on March 14, 2025. The resource persons were Prof. C.H Ishwara Chandra, NCRA-TIFR, Dr. K. G Biju, Associate Professor, WMO college, Muttil and Mr. Sudheesh T P, Research Scholar, Christ University, Bangalore.

List of publications by using ICARD facilities

1. Solar Wind-Magnetosphere Coupling Efficiency and its Dependence on Solar Activity During Geomagnetic Storms of 23-24 Solar Cycles, V. M. Ashna, Ankush Bhaskar, G. Manju, R.Sini , **Journal of Geophysical Research: Space Physics: Volume 129, Issue 8, 2024.**
2. Long term X-ray spectral variations of the Seyfert-1 galaxy Mrk 279, K. Akhila , Ranjeev Misra , Savithri H. Ezhikode , K. Jeena, **Research in Astronomy and Astrophysics, Volume 24, No 6, 2024.**
3. Modelling the energy dependent X-ray variability of Mrk 335, K. Akhila, Ranjeev Misra, Rathin Sarma, Savithri H. Ezhikode, K. Jeena, **Journal of High Energy Astrophysics, Volume 45, 2025.**
4. Strong Gravitational Lensing and Shadows by Quantum Schwarzschild Black Hole in Homogeneous Plasma, V. P. Rukkiya, R. Sini, **International Journal of Theoretical Physics, 64-3, 2025.**

Outreach programmes arranged by ICARD

1. Painting competition and Essay writing competition was organized for college students on 9th August 2024, in connection with the National Space day celebrations.
2. Quiz competition and painting competition was organized for school students on 13th August 2024, in connection with the National Space day celebrations.
3. Public talk on 'Basics of Rocket Science' was delivered by Mr. Siju. A.K, Scientist, VSSC, on 4th October 2024.
4. Public talk by Prof. Dhruba J Saikia, Astrophysics and Space Science former head, NCRA-TIFR, was held on 11th December 2024, on the topic 'The Milky Way'.

Department of Physics, University College Thiruvananthapuram, Kerala

Coordinator:
Dr. Prince P R.

Research Area

The primary research area that the ICARD facilitates include Solar Physics, Solar-terrestrial Physics & Space weather (magnetospheric & ionospheric studies)

Research work done in ICARD

Currently research is focused on two areas –Space weather and solar phenomena.

For a better understanding of space weather, it is essential to study ionospheric electrodynamics and density profiles, with changes in geomagnetic activity. The main focus is the study of ionosphere models with respect to geomagnetic changes. Analysis using Weimer ionospheric electrodynamics model is done extensively. Influence of solar flares and volcanic eruptions, on the ionosphere is also addressed.

On studies on solar phenomena, understanding CMEs is quite vital. We are working on the acceleration regime of the CME within a given solar radius and try to observe how this varies over the solar cycle. We examine whether there exists any observable significance in the CME acceleration over various cycles.

Workshops/schools organised by ICARD

ICARD has organised 3 programmes in the 5 months' period since its inception.

Invited Lecture: The Search for a new planet in the Solar System.

The lecture was delivered by Prof. Surhud More, IUCAA, on 18th January 2025. The talk was attended by 40 students and teachers.

Science Day Celebrations

ICARD organized the National Science Day Celebrations 2025 on 25th February 2025.

- The first invited lecture was 'Fascinating Science', delivered by Dr. Sibi K. S., University of Kerala.
- In the second invited talk was 'The Large-Scale Structure of the Universe', Dr. Anand Narayanan, Indian Institute of Space Science and Technology (IIST).
- The third lecture by Dr. Prince P. R., Co-ordinator, ICARD.

A total of 11 presentations were delivered, demonstrating a diverse range of scientific topics. The celebrations culminated in a Sky Watching Session, organized in collaboration with the IIST Astronomy Club. A total of 60 students attended the Celebrations.

Invited Lecture: Solar wind, climate and Earth by Prof. Bruce Leyborne, Director, Geoplasma Research Institute, Colorado, USA on 07 March 2025. The session was attended by 50 participants

List of publications by using ICARD facilities

Prince P R, Aswini Thampy S L and Sreebala P S, Study of Ionospheric response to intense Solar Flares in the ascending half of the solar cycle 25, (preprint), accepted for Oral presentation in the General Assembly of European Geosciences Union (EGU25) to be held in Vienna, Austria, 27 April—2 May 2025, DOI: 10.5194/egusphere-egu25-375

Sky watch

The Science Day celebrations in ICARD on 25th February 2025, culminated in a Sky Watch Session, organized in collaboration with the IIST Astronomy Club. Under expert guidance, participants had the opportunity to observe celestial objects, including the Moon, planets, and star clusters, through high-powered telescopes. This session deepened participants' appreciation for observational astronomy and sparked discussions on astrophysical phenomena

Department of Physics, Newman College Thodupuzha, Kerala

Coordinator:
Dr. Joe Jacob

Areas of research

Radio Astronomy, X-ray Astronomy

Research work done at ICARD

Research Scholar Mrs. Aparna Raj conducted a detailed spectral and morphological analysis of a subset of restarted radio source candidates, identified using the spectral curvature method. This analysis was carried out using high-sensitivity radio observations from the upgraded Giant Metre wave Radio Telescope (uGMRT) in Pune. Mrs. Neha P. R. extended her research by analysing the spectral variability of the X-ray Source Ark 564. Her study revealed that the positive correlations among various best-fit model parameters indicated the presence of internal structural processes within the active galactic nucleus (AGN).

Conferences, Meetings and workshops

1. The National Conference on Classical and Quantum Gravity was held from November 5 to 7, 2024, at the Department of Physics, Cochin University of Science and Technology (CUSAT), Kochi.

2. **The Tenth Southern Regional Astronomy Meeting: Astronomy Research: Opportunities and Challenges** was held from January 31 to February 2, 2025, at the Cochin University of Science and Technology (CUSAT), Kochi, Kerala.

3. The Department of Physics, St. Thomas College, Ranni, in collaboration with ICARD, Newman College, Thodupuzha, and the Centre for Excellence in Astronomy and Astrophysics, CHRIST (Deemed to be University), Bangalore, organized a three-day workshop on Optical Astronomy from February 28 to March 2. A total of 39 students from 15 colleges participated in the workshop, which was held at St. Thomas College, Ranni.

Outreach program (including public lectures / sky watch) organised by ICARD

International Moon Day Celebration – 25 July 2024

The International Moon Day was celebrated by ICARD on 25 July 2024 with the screening of the documentary *The Moon Landing* by our alumnus, Ms. Immy Tresa Thomas (Teacher, St. George H.S., Muthalakodam). This was followed by a seminar on *Moon Explorations* conducted by Mr. Manikandan V. M., a student of the college. A poster competition was also held, with 11 students participating.

Seminar on "The Lives and Deaths of Stars" – 13 January 2025

ICARD, in collaboration with the Department of Physics, Newman College, Thodupuzha, organized a seminar titled *The Lives and Deaths of Stars* on 13 January 2025. Ms. Nidhi Sabu, Research Scholar at CHRIST University, Bangalore, and an alumna of the college, served as the resource person. The session offered valuable insights into stellar evolution and greatly enriched the participants' knowledge and interest in the subject.

Seminar on "The Cosmic Story of Evolution" – 14 February 2025

To celebrate the scholarly excellence of Dr. Biju K. G., ICARD organized a seminar on *The Cosmic Story of Human Creation* on 14 February 2025. The session explored the origin of humans from a cosmic perspective, sparking curiosity about the universe's role in human existence and inspiring students to pursue further studies in cosmology and astrophysics.

Sky Watch Programme – 28 January 2025

A sky watch programme was conducted at the college on 28 January 2025, with around 100 students in attendance. The event was followed by an astrophotography training session, in which five students participated.

Department of Physics, Fergusson College (Autonomous), Pune

Coordinator:
Dr. Raka Dabhade

Exhibition "On the Shoulders on Giants" between January 15 - 16, 2025

The Exhibition was a two-day event in which about sixty undergraduate students successfully conducted the event in January. The Exhibition was open to all and we had **800+ visitors (registered entries)** plus some local school teachers with their school children groups of 10 to 30.

The Exhibition was divided into 10 Groups/ themes showcasing the gradual evolution of Physics:

Group 1: The Dawn of Discoveries:

Group 2: The EM Visionary:

Group 3: The Electric Mavericks:

Group 4: Planck and Einstein: Shaping the Quantum World:

Group 5: Legacy of Curie and Meitner:

Group 6: The Atomic Paradox:

Group 7: The Uncertainty Story:

Group 8: CV Raman - Unlocking Light's Secrets:

Group 9: The Theory of Everything:

Group 10: Unveiling the Cosmos:

About sixty undergraduate volunteers prepared the charts and handmade models and explained it to the public / visitors. Models / Exhibits made by the students included:

National students' seminar on Frontiers in Physics XVIIth between February 10 - 11, 2025

We had total 161 registrations of which 51 were from colleges other than Fergusson College and from 14 different institutions in and out of Pune. We also had an outreach session on the last day on **"LIGO India Outreach Program"** by Dr. Debarati Chatterjee and Saurabh Salunke. The inaugural talk was delivered by **Prof. Naresh Dadhich**, Emeritus Professor and former Dir. IUCAA, Pune. Topic: "**An unified view of the four fundamental forces"**.

The **Fergusson College Radio Astronomy School 2025** was successfully conducted from February 17 - 24, 2025 under IUCAA Center for Astronomy Research and Development - ICARD**.**

The school received seventy-eight applications from various colleges and institutes, out of which forty candidates (both UG-PG) were shortlisted for participation. The coordinators for RAS were Manish S. Hiray and Gajanan D. Harale.

Department of Physics, D.D.U. Gorakhpur University Gorakhpur, Gorakhpur Uttar Pradesh

Coordinator:
Professor Shantanu Rastogi

Area of Research

Infrared observations of stars, Circumstellar and Interstellar Medium, Molecules of Astrophysical importance, Star clusters, Gravity and Dark Matter, Atmospheric aerosols, Trace gases in planetary atmospheres etc.

Brief report about the research work done in ICARD

Amit Pathak, BHU and Shantanu Rastogi, DDUGU have studied various aspects of astrophysical infrared emission features and their possible carrier polycyclic aromatic hydrocarbon (PAH) molecules. Study of Globular Clusters using observations from ARIES, Nainital and GAIA data is being carried out by Apara Tripathi, DDUGU. Theoretical studies on chemistry of formation of pre-biotic molecules in interstellar medium are being done by Alka Mishra, LU. Rajesh Kumar, DDUGU studies gravitational collapse and interacting models of dark matter and dark energy. Analysis of Astrosat observations by Sanjay Pandey, LBS Gonda. Continuous monitoring of atmospheric aerosols at Gorakhpur and study of satellite data on atmospheric trace gases are being carried out by Prabhunath Prasad and Shantanu Rastogi, DDUGU.

Publications:

1. Anisotropic model of stellar objects in modified f (R) gravity; **R Kumar**, SK Maurya, A Errehymy, K Myrzakulov, Z Umbetova, VN Pathak; Chinese Journal of Physics 92, 1-22, 2024.
2. Anisotropic Durgapal-Fuloria compact stars in f (R) gravity; **R Kumar**, SK Maurya, A Errehymy, G Mustafa, AH Abdel-Aty, HI Alrebdi, Mona Mahmoud; Nuclear Physics B 1008, 116690, 2024.
3. A new perspective on gravitational collapse: a comprehensive analysis using parametrization; **R Kumar**, A Jaiswal, SK Srivastava, SKJ Pacif; The European Physical Journal C 84 (9), 956, 2024.
4. Re-Examining Berman's Parametrization of the Hubble Parameter in the Context of Late-Time Acceleration; KR Mishra, **R Kumar**, SKJ Pacif, Astrophysics 67 (2), 246-265, 2024.
5. Significance of a quadratically varying deceleration parameter in scalar field-dominated model and cosmic acceleration; KR Mishra, H Chaudhary, **R Kumar**, Z Nekouee, SKJ Pacif; Modern Physics Letters A 39 (19n20), 2450087, 2024.
6. Human resource development in astronomy: An Indian perspective; JS Bagla, M Das, A Datta, R Gogoi, A Hota, A Kembhavi, ... **S Rastogi**, ...; Journal of Astrophysics and Astronomy 46 (1), 1-9, 2025.
7. Research on the interstellar medium and star formation in the Galaxy: An Indian perspective; B Mookerjea, G Maheswar, K Acharyya, ... **S Rastogi**, ...; Journal of Astrophysics and Astronomy 46 (1), 1-26, 2025.
8. Dynamical and Microphysical Aspects of Two Distinct Precipitation Systems in the Himalayas with 206.5 MHz Radar and WRF Model; A Rajput, N Singh, J Singh, A Kumar, **S Rastogi**; Earth and Space Science 11 (5), e2023EA003213, 2024.
9. Insights of Boundary Layer Turbulence Over the Complex Terrain of Central Himalaya from GVAX Field Campaign; A Rajput, N Singh, J Singh, **S Rastogi**; Asia-Pacific Journal of Atmospheric Sciences 60 (2), 143-164, 2024.

Activities/Outreach programmes:

1. Dr. Alka Mishra, Lucknow University, Lucknow, visited ICARD on 28 March 2024, discussed about 'Interstellar Biomolecules' with M.Sc. students.
2. Dr. Narendra Singh, ARIES, Nainital, visited ICARD on 13 May 2024, discussed about 'Atmosphere Science' with MSc and PhD students.
3. Workshop on 'Space Sciences' was held on 17 Sep 2024 for MSc and BSc students. Prof. Durgesh Tripathi, IUCAA and Dr. Mukunda Gogoi, SPL, ISRO were resource persons.
4. Workshop on 'Gravitation and Cosmology' was held during 23 – 25 Oct 2024 for BSc, MSc and PhD students in the Department of Mathematics and Statistics. Dr. Apratim Ganguly (IUCAA) and Dr. Rajesh Kumar coordinated the organisation of the workshop. Other resource persons included Prof. Sobenoy Chakraborty (Jadavpur University, Kolkata), Dr. Jibitesh Dutta (NEHU, Shilong) and Prof. Shantanu Rastogi.
5. Prof. Christian Woehler, TU Dortmund, Germany, visited ICARD and delivered a special Lecture on "Lunar surficial water using orbital IR imagery" on 20 Nov 2024 in the Department of Physics.
6. Prof. Shiv Kumar Sharma, University of Hawaii, USA, visited ICARD and delivered a special lecture on "Application of Raman Spectroscopy for Planetary Science and in Other Fields" on 20 Feb 2025 in the Faculty of Science.
7. Workshop on 'Stellar Evolution and Pulsation Modelling' was held during 24 – 25 Mar 2025 for MSc students. Dr. Anupam Bharadwaj (IUCAA), Dr. Apra Tripathi and Dr. Prabhunath Prasad coordinated the organisation of the workshop. Other resource persons included Dr. Prasanta Bera (BHU), Dr. Raj Prince (BHU), Prof. Shantanu Rastogi and Dr. Sushmita Das (IUCAA).

Department of Physics, University of Lucknow, Lucknow

Coordinator:
Professor Murli Manohar Verma

Area of research

Broad areas at Department of Physics, UoL include cosmology and astrophysics, High energy Physics, Advanced material sciences, Liquid crystals, quantum optics etc. The research is carried out in both, theory and experiments.

Specific to Astronomy and Astrophysics:

The Department of Physics was accorded the ICARD status in December 2024. We have explored the suppression of the scalar modes of polarisation of gravitational waves travelling across the evolving galaxies. This is done in the modified f(R) gravity background. The observation of such modes is found to be dominantly suppressed by a chameleon mechanism in the gas rich environment of the galaxies. The degree of suppression is found to constrain the future observations which are dominated by tensor modes. It is proposed that the influence on the polarisation by the varying density galactic backgrounds serves as a new and strong approach to distinguish the LambdaCDM model from the alternative gravity theories. We show consistency checks of our results with the current galactic observations.

Research work done in ICARD:

Recently we are working out speed of gravitational waves in the framework of Horndeski theories.

Workshop held at ICARD

Henceforth, due to lack of time in doing the formal procedures the following activities have been held without IUCAA financial support.

Two-day Workshop on Basic Astronomy and Astrophotography

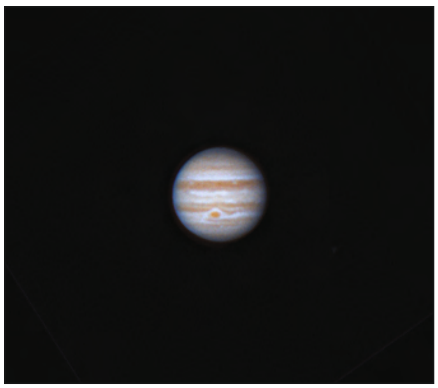
After we received the intimation dated 04.11.2024 about the ICARD status being accorded to us, and even before the status of ICARD was formally accepted by Lucknow University on 17.12.2024, out of enthusiasm, a two-day Workshop on Basic Astronomy and Astrophotography conducted by MSc students, Harshwardhan Pathak and Om Prakash Mishra during December 11 - 12, 2024. This was an engaging student-to-student interaction organised at the Physics Department of Lucknow University. The workshop aimed to ignite curiosity about the universe through a hands-on learning experience, focusing on foundational concepts in spherical astronomy, stellar evolution, and general astronomy.

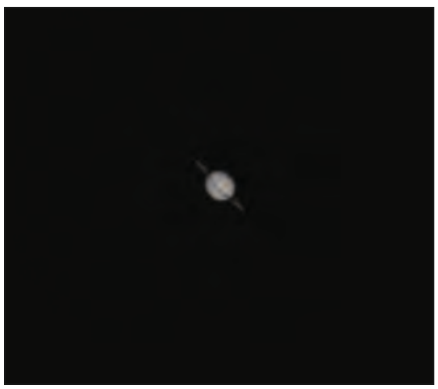
Astronomy Outreach Programs by ICARD

During December 2024 to April 2025, the University of Lucknow under ICARD conducted a series of astronomy outreach programs aimed at fostering scientific curiosity and hands-on learning among students and the community.

Key Activities:

- Celestial Observations: Participants observed planets such as Venus, Saturn, and Jupiter, and detailed lunar craters using the Skywatcher 8-inch Dobsonian telescope.
- Telescope Operation: Students learned the basics of manual telescope handling, including alignment, focusing, and observational techniques.





- Constellation Identification: Guided sessions on constellation hunting helped participants identify major star patterns and understand their historical and mythological significance.
- Educational Briefings: Prior to observations, briefings on planets, deep sky objects, and constellations provided essential context for the night sky sessions.

These programs effectively combined theoretical knowledge with practical observation, inspiring students to explore the universe beyond the classroom.

Educational Visit to ARIES (Aryabhatt Research Institute for Observational Sciences), Nainital, Uttarakhand (March 24-27, 2025)

A group of 7 enthusiastic students from ICARD of Lucknow University had the incredible opportunity to visit the Aryabhatt Research Institute for Observational Sciences (ARIES) in Nainital, Uttarakhand.

Achievements of students who are connected with ICARD

- **Harshwardhan Pathak**, a Master's student in Physics at the University of Lucknow, has achieved significant milestones in astrophotography and scientific modeling between December 2024 and April 2025.
- AstroCamera 2024: In January 2025, Pathak received an Honorary Mention in the international AstroCamera 2024 competition for his composite image of the Statue of Liberty Nebula (NGC 3576) and the Helix Nebula (NGC 7293).
- NASA Astronomy Picture of the Day (APOD): In February 2025, his image of the Horsehead Nebula (Barnard 33) was featured as APOD, highlighting his expertise in capturing deep-sky objects.
- AAPOD2 (Amateur Astronomy Picture of the Day): His work also received recognition on AAPOD2, further cementing his status in the astrophotography community.
- BBC Sky at Night Yearbook: Pathak's image of the Pleiades star cluster was published in the 2025 edition of the BBC Sky at Night Yearbook, showcasing his talent in capturing stellar formations.
- DIY Photography Interview: In March 2025, he shared his astrophotography journey and insights in an interview with DIY Photography, discussing his experiences with remote astrophotography and his creative process.
- Best Model Award on National Science Day: Pathak, alongside his team member **Durga Yadav**, was awarded the **Best Model Mention** during **National Science Day** for their innovative model of the Laser Interferometer Gravitational-Wave Observatory (LIGO)
- **Ayushi Maurya**, a second-semester M.Sc student in the Department of Physics at the University of Lucknow, actively participated in the inter-college fest 'OAJ 2025', organized by National PG College. She secured the 2nd prize in the poster-making competition.

Centre for Cosmology, Astrophysics and Space Science (CCASS), GLA University, Mathura

ICARD Coordinator:
Professor Anirudh Pradhan

Area of research

Astronomy, Astrophysics, Cosmology, History and Philosophy of Science

Research done in ICARD

The ICARD at GLA University is engaged in the field of Cosmological modelling with the General theory of relativity and modified theories of gravity. The theoretical cosmological modelling has been supplemented with data analytic approaches to carry out research activities. The research activities related to the modelling and simulation of the Astrophysical phenomena have been presented in different publications. The theoretical studies of black holes, neutron stars, strange stars, wormholes and compact objects have been conducted in the published papers. The members are also involved in conducting studies of Active galactic nuclei as well as BL lac objects using different approaches. The research works related to history and philosophy of science have also been given importance in the ICARD, GLA University, Mathura.

Research publications

1. G. Mustafa, F. Javed, S.K. Maurya, **S. Ray**, Possibility of stable thin-shell around wormholes within string cloud and quintessential field via the van der Waals and polytropic EOS, *Chinese Journal of Physics*, **88**, 32-54 (2024)
2. **A. Singh**, Qualitative study of anisotropic cosmologies with inhomogeneous equation of state, *Chinese J. Phys.* **88**, 865-878 (2024)
3. **A. Singh**, Lyra cosmologies with the dynamical system perspective, *Phys. Scr.* **99**, 045011 (2024)
4. **D.C. Maurya**, Modified f(Q,C) gravity dark energy models with observational constraints, *Mod. Phys. Lett. A* **39**, 2450034 (2024)
5. **D.C. Maurya**, R. Myrzakulov, Transit cosmological models in F(R,T) gravity theory, *Eur. Phys. J. C* **84**, 534 (2024)
6. S.R. Chowdhury, D. Deb, F. Rahaman, **S. Ray**, Finslerian extension of an anisotropic strange star in the domain of modified gravity, *Eur. Phys. J. C* **84**, 472 (2024)
7. S.K. Maurya, H. Chaudhary, A. Ditta, G. Mustafa, **S. Ray**, Study of self-bound compact stars in f(T) gravity and observational constraints on the model parameters, *Eur. Phys. J. C* **84**, 603 (2024)
8. T. Tangphati, D.J. Gogoi, **A. Pradhan**, A. Banerjee, Investigating stable quark stars in Rastall-Rainbow gravity and their compatibility with gravitational wave observations, *J. High Energy Astrophys.*, **42**, 12-20 (2024)
9. **D.C. Maurya**, R. Myrzakulov, Exact cosmological models in metric-affine F(R, T) gravity, *Eur. Phys. J. C* **84**, 625 (2024)
10. G. Mustafa, S.K. Maurya, A. Ditta, **S. Ray**, F. Atamurotov, Circular orbits and accretion disk around AdS black holes surrounded by dark fluid with Chaplygin-like equation of state, *Eur. Phys. J. C* **84**, 690 (2024)
11. T. Tangphati, A. Banerjee, I. Sakalli, **A. Pradhan**, Quark stars in Rastall gravity with recent astrophysical observations, *Chinese J. Phys.* **90**, 422-433 (2024)
12. S. Das, **S. Ray**, M. Khlopov, B.K. Parida, K. Chakraborty, S.K. Pal, A study on anisotropic compact stellar model under color-flavor locked equation of state, *Chinese J. Phys.* **90**, 474-493 (2024)
13. **A. Pradhan**, Archana Dixit, M. Zeyauddin, and S. Krishnannair, A flat FLRW dark energy model in f(Q,C)-gravity theory with observational constraints, *Int. J. Geom. Methods Mod. Phys.* **21**, 2450167 (2024)
14. G.K. Goswami, J.K. Singh, R. Rani, **A. Pradhan**, FLRW cosmology in Weyl type f(Q) gravity and observational constraints, *J. High Energy Astrophys.* **43** 105-113 (2024)
15. **D.C. Maurya**, Transit cosmological models in non-coincident gauge formulation of f(Q,C) gravity theory with observational constraints, *Gravit. Cosmol.* **30**, 330-343 (2024)
16. K. Ghaderi, **A. Pradhan**, A. Mahmoodzadeh, Stability and phase transition of black holes in Einstein-Maxwell-dilaton gravity, *Nucl. Phys. B* **1006**, 116660 (2024)
17. S. Mandal, **A. Singh**, R. Chaubey, Late-time constraints on barotropic fluid cosmology, *Phys. Lett. A* **519**, 129714 (2024)
18. S.K. Maurya, A. Errehymy, K.N. Singh, A. Aziz, S. Hansraj, **S. Ray**, Modeling Compact Object Mergers GW190814 and GW200210 and Other Self-bound Compact Stars with Dark Matter Induced by Gravitational Decoupling and Its Significance to the Mass Gap, *ApJ* **972**, 175 (2024)
19. S. Chaudhary, S.K. Maurya, J. Kumar, **S. Ray**, Stability analysis of wormhole solutions in f(Q) gravity utilizing Karmarkar condition with radial dependent redshift function, *Astropart. Phys.* **162**, 103002 (2024)
20. R. Garg, G.P. Singh, A.R. Lalke, **S. Ray**, Cosmological model with linear equation of state parameter in f(R,Lm) gravity, *Phys. Lett. A* **525**, 129937 (2024)
21. Rui-Yan Chen, F. Javed, G. Mustafa, S.K. Maurya, **S. Ray**, Dual effect of string cloud and dark matter halos on particle motions, shadows and epicyclic oscillations around Schwarzschild black holes, *J. High Energy Astrophys.* **44**,

172-186 (2024)

22. L.K. Sharma, S. Parekh, **S. Ray**, A.K. Yadav, Constraining anisotropic universe under f(R,T) theory of gravity, *J. High Energy Astrophys.* **44**, 457-467 (2024)
23. **A. Singh**, Role of dynamical vacuum energy in the closed universe: implications for bouncing scenario, *Gen. Relativ. Gravit.* **56**, 138 (2024)
24. S. Kiroriwal, J. Kumar, S.K. Maurya, **S. Ray**, Wormhole configuration with viable equation of state in f(Q) gravity, *Phys. Dark Uni.* **46**, 101559 (2024)
25. T. Tangphati, I. Sakalli, A. Banerjee, **A. Pradhan**, Behaviors of Quark Stars in the Rainbow Gravity Framework, *Phys. Dark Univ.* **46**, 101610 (2024)
26. Y. Feng, A. Ditta, G. Mustafa, S.K. Maurya, A. Mahmood, **S. Ray**, F. Atamurotov, Testing the non-commutative charged Schwarzschild black hole surrounded by perfect fluid dark matter for thermodynamical features and weak gravitational lensing, *Phys. Dark Uni.* **46**, 101685 (2024)
27. **D.C. Maurya**, Late-time accelerating cosmological models in f(R,Lm,T)-gravity with observational constraints, *Phys. Dark Uni.* **46**, 101722 (2024)
28. **D.C. Maurya**, K. Yesmakhanova, R. Myrzakulov, G. Nugmanova, FLRW Cosmology in Metric-Affine F(R,Q) Gravity, *Chinese Phys. C* **48**, 125101 (2024)
29. A. Banerjee, S. Hansraj, **A. Pradhan**, A. Errehymy, Is dark energy necessary for the sustainability of traversable wormholes?, *Chinese Phys. C* **49**, 015101 (2025)
30. A. Banerjee, I. Sakalli, B. Dayanandan, **A. Pradhan**, Quark stars in f(R,T) gravity: Mass-to-radius profiles and observational data, *Chinese Phys. C* **49**, 015102 (2025)
31. A. Banerjee, **A. Pradhan**, I. Sakalli, A. Dixit, Properties of interacting quark star in light of Rastall gravity, *Class. Quant. Grav.* **42**, 025008 (2025)
32. S. Gupta, A. Dixit, **A. Pradhan**, K. Ghaderi, f(T, TG) gravity theory: observational constraints for Barrow holographic dark energy with Hubble and Granda-Oliveros cutoff, *Phys. Scr.* **100**, 015035 (2025)
33. A.K. Singha, A. Sardar, U. Debnath, **A. Pradhan**, Cosmological dynamics of FRW universe in presence of tachyonic field, *Phys. Scr.* **100**, 015038 (2025)
34. **A. Singh**, Dynamical systems of modified Gauss–Bonnet gravity: cosmological implications, *Eur. Phys. J. C* **85**, 24 (2025)
35. R. Mandal, U. Debnath, **A. Pradhan**, Dynamical system analysis for extended f(P) gravity coupled with scalar field, *Eur. Phys. J. C* **85**, 80 (2025)
36. F. Rahaman, R. Amin, M. Hasan, A. Islam, **S. Ray**, A. Aziz, N.A. Pundeer, Gravitational Deflection of Massive Body Around Global Monopole, *Fortschr. Phys.* **73**, 2400007 (2025)
37. V.C. Dubey, U.K. Sharma, **S. Ray**, A. Sanyal, Study of cosmological dark energy models under f(Q) gravity, *Phys. Dark Uni.* **47**, 101736 (2025)
38. T. Tangphati, G. Panotopoulos, A. Banerjee, **A. Pradhan**, Properties of white dwarf stars within Rainbow gravity, *Phys. Dark Uni.* **47**, 101741 (2025)
39. N. Myrzakulov, S.H. Shekh, **A. Pradhan**, Probing dark energy properties with Barrow Holographic Model in f(Q,C) gravity, *Phys. Dark Uni.* **47**, 101790 (2025)
40. **A. Singh**, S. Mandal, R. Chaubey, R. Raushan, Observational constraints on the expansion scalar and shear relation in the Locally rotationally symmetric Bianchi I model, *Phys. Dark Uni.* **47**, 101798 (2025)

Outreach program (including public lectures / sky watch) organised by ICARD

Pt. Deen Dayal Upadhyay Govt. Model Inter College, Jait, Mathura on the topic "Big Bang: The Beginning of Universe" on date 14 February, 2025.

A sky-watching event using Telescope was organized in evening for students and faculties of university on Date: 06 March, 2025.

Department of Physics, Institute of Science, Banaras Hindu University, Varanasi,

ICARD Coordinator:
Dr. Raj Prince

Areas of research

- Extra galactic astrophysics
- High-energy astrophysics
- Studies of compact objects
- Magneto-Hydrodynamics simulation in the solar atmosphere
- Interstellar dust and interstellar Polycyclic Aromatic Hydrocarbon (PAH) molecules

Research conducted

A multi-wavelength study of different AGNs has been performed. Study on Ton 599 reveals the possible disk-jet connection (in press). A fast temporal variability has been found in BL Lacertae. Classification of three BCUs, namely PKS B0027-024, 4C +15.05, and PMN J0143-3623 has been done based on spectral and temporal analysis. Broadband temporal and spectral study is performed for OP 313. All other work is under review in international refereed journals.

Workshop organized by the Department of Physics, BHU, Varanasi

ICARD Department of Physics organized a workshop entitled "High Energy Astrophysics Workshop" from 25 to 27 November 2024. Total 36 out-stationed students from all over India and 35 in-house students participated in the workshop.

Publications

1. "From microquasars to AGN: A uniform jet variability" Ajay Sharma, Raj Prince, and Debanjan Bose, Phy Rev D, 2025 in press.
2. "On the origin of multifrequency temporal and spectral variability in Ton 599" S. Maurya, J. Majumdar, Varun, N. Sahu, Raj Prince, Pub of the Astronomical Society of Australia, 2025, in press.
3. "Dark and bright sides of the Broad Line Region clouds as seen in the FeII emission of SDSS RM 102" A. Floris, A. Pandey, B. Czerny, M. L. Martinez Aldama, S. Panda, P. Marziani, Raj Prince, 2025, Astronomy and Astrophysics, in press.
4. "Modeling multiband SEDs and light curves of BL Lacertae using a time-dependent shock-in-jet model" R. Khatoon, M. Bottcher, Raj Prince, 2025, ApJ, 974, 233.
5. "Investigating C–D out-of-plane vibrational modes in PAHs as a tool to study interstellar deuterium-containing PAHs", M. Buragohain, Amit Pathak, T. Onaka, A. Vats, I. Sakon, Mon. Not. Royal Astron. Soc., 2025, in press.
6. "Research on the Interstellar Medium and Star Formation in the Galaxy: An Indian Perspective", B. Mookerjea, Maheswar G., K. Acharyya, T. Baug, P. Datta, J. Jose, D. K. Ojha, J.D. Pandian, N. Roy, M. Samal, S. Sharma, A. Soam, S. Vig, A. Das, L. Dewangan, S. Dutta, C. Eswariah, L. Majumdar, K.K. Mallick, S. Monda, J.P. Ninan, N. Panwar, Amit Pathak, S. Rastogi, D. Sahu, A. Tej, Veena. V.S, Journal of Astrophysics and Astronomy, 2025, 46, 3.
7. "Theoretical Rotational and Vibrational Investigation of Oxygen-Functionalized Interstellar PAHs", S. Mishra, A. Vats, S. Srivastav, Amit Pathak, P.J. Sarre, T. Onaka, I. Sakon, Mon. Not. Royal Astron. Soc., 2025, 536, 3357.

ICARD, Department of Physics, Cooch Behar Panchanan Barma University (CBPBU)

ICARD Coordinator:
Dr Ranjan Sharma

Area of Research:

Astrophysics, Cosmology and Particle physics, Classical and quantum gravity: Exact solutions; Compact stars; Gravitational collapse; Dark matter and Dark energy; Tidal effects; Modified theories of gravity.

List of workshops/schools organised by ICARD, CBPBU

1. IUCAA Centre for Astronomy Research and Development (ICARD), Department of Physics, Cooch Behar Panchanan Barma University (CBPBU) organized a three-day national conference titled "Gravity@2024" during 18 – 20 December 2024. The conference's scientific programme covered a broad range of areas in gravitational physics, including the physics of compact stars, tests of the general theory of relativity, modified theories of gravity, galaxy formation and evolution, observational

astronomy and cosmology.
2. The ICARD, Cooch Behar Panchanan Barma University (CBPBU) facilitated a lecture series engaging Prof. Kanak Saha, IUCAA, to teach a cosmology course at the Department of Physics, CBPBU during the period from 19 May 2024 to 10 June 2024.

List of publications by using ICARD facilities

Fifteen research articles in refereed international journals have been published by the faculty members (Visiting Associates of IUCAA) and research scholars of CBPBU working in the field of astrophysics and cosmology during this period. The list of publications is given below:

1. *Compactness bound of Buchdahl-Vaidya-Tikekar anisotropic star in D ≥ 4 dimensional spacetime*, Samstuti Chanda and **Ranjan Sharma**, Gen. Relativ. Grav. (2024) **56**:41. DOI: https://doi.org/10.1007/s10714-024-03231-x

2. *Anisotropic star with a linear equation of state (EOS)*, R. Patel; B. S. Ratanpal and **R. Sharma**; Indian J. Phys. (2025), **99(2)**, 741. DOI: https://doi.org/10.1007/s12648-024-03297-y.

3. *Anisotropic generalization of charged isotropic spheres via double equation of state*, S. Thirukkanesh, Sunil D. Maharaj and **Ranjan Sharma**, Eur. Phys. J C (2024) **84**:872. DOI: https://doi.org/10.1140/epjc/s10052-024-13199-2

4. *Impact of spacetime curvature on the physical behaviour of Vaidya and Tikekar (VT) type anisotropic compact objects*, Lipi Baskey, Shyam Das, **Ranjan Sharma** and Farook Rahaman, New Astronomy (2024) **108**, 102164. https://doi.org/10.1016/j.newast.2023.102164

5. *Exploring quaternary Heusler alloys RhX'ZrZ (X' = Cr, fe; Z = Si, Ge) for advanced spintronic devices: A first-principles approach*, Kunal Labar, **Ranjan Sharma** and A. Shankar, Computational Condensed Matter (2025) **42**, e10006. DOI: https://doi.org/10.1016/j.cocom.2025.e01006

6. *Model of a Static, Spherically Symmetric, Charged Star with Anisotropic Stress and Its Complexity Analysis*, Arpita Ghosh, Satarupa Barman, K. Komathiraj and **Ranjan Sharma**, International Journal of Theoretical Physics (2025) **64**:77; DOI: https://doi.org/10.1007/s10773-025-05941-7

Department of Physics, Aliah University, Kolkata

ICARD Coordinator:
Prof. Md. Mehedi Kalam

Area of Research

General Relativity, Theoretical Astrophysics, Compact stars; Dark matter; Alternative Theory of Gravity; Wormhole Physics, Cosmology.

Aliah University's Department of Physics has started functioning as a host of ICARD on and from September 14, 2022, after receiving the approval from the competent authority. The Department has enhanced its Astrophysics program, introducing General Relativity, Astrophysics, and Cosmology courses. This offers M.Sc. students a comprehensive 12-credit course alongside a 4-credit project in Astrophysics and Cosmology, starting from the 2022-23 academic session to till date. The department has got the renewal of ICARD for the session 2024-26.

Research work done in ICARD

The members associated with ICARD, Aliah University have worked on different issues related to the areas of Astrophysics and Cosmology. We have, together with other associates and members, and foreign collaborators consider to study the solutions which describe wormholes in the halos of dwarf and massive spiral galaxies with different morphologies, masses, sizes and gas fractions by taking observed flat rotation curves as input. We assume Singular Isothermal Sphere (SIS) dark matter density profile. This result confirms the possible existence of wormholes in both dwarf and massive spiral galaxies.

Also, we theoretically construct a (2 + 1)-dimensional rotating thin shell wormhole using the Darmois-Israel junction formalism by cutting and pasting two rotating hairy black hole spacetimes in (2+1)-dimensions. This thin shell wormhole's validity has been checked by analyzing the energy conditions, specifically, the weak and null energy conditions. We further discuss different physical features of the constructed wormhole, viz., the nature of the gravitational field, the equation of state at the throat, and the time evolution of the throat radius. In continuation of taking (2+1) dimensions, we try to modelled low-mass strange stars using the Tolman IV metric. Important observation of our study was that the presence of attractive or positive anisotropic force is the cause for the lower mass of the strange stars. We have also found that the cosmological constant has a significant role in the mass-radius relationship of the stars.

Also, we attempt to construct a regular

gravastar model using the UV corrected framework of Loop Quantum Cosmology(LQC). We find that a stable gravastar model can be constructed with a number of unique features: (i) no thin shell approximation needs to be invoked to obtain solutions in the shell which can be considered to be of a finite thickness, (ii) the central singularity of a self-gravitating object can be averted by a bounce mechanism, such that the interior density of the gravastar reaches a maximum critical density and cannot be raised further due to an operative repulsive force, (iii) the inherent isotropy of the effective fluid description does not prevent the formation of a stable gravastar, and anisotropic pressures is not an essential requirement.

In another article, we study the slowly rotating neutron stars in $f(R, T)$ gravity based on Hartle-Thorne formalism. We first consider the simplest matter-geometry coupled modified gravity, namely $f(R, T) = R + 2\chi T$. We compute the mass, radius, moment of inertia, change in radius, and binding energy due to rotation, eccentricity, quadrupole moment, and the tidal love number. The quantities, which are of the second order in angular velocity, like change in radius and binding energy due to rotation, eccentricity, and quadrupole moment, deviate more from their corresponding general relativistic counterparts in lighter neutron stars than heavier ones. Whereas the moment of inertia, which is of the first order in angular velocity, in $f(R, T) = R + 2\chi T$ modified gravity, barely diverges from the general relativistic one. The Equation of state-independent I-Love-Q relation retains in this $f(R, T)$ modified gravity, and it coincides with the general relativistic ones within less than one percent even for the maximum allowed coupling parameters. We also study the slowly rotating neutron star in $f(R, T) = R + \alpha R^2 + 2\chi T$ up to first order their angular velocity. We calculate the mass, radius, and moment of inertia of neutron stars in this modified gravity. The results show that the impact of the matter-geometric coupling parameter is greater on lighter neutron stars in both of these modified gravity models.

Group Photo of the Seminar Lecture

Colloquia/Seminars organized by ICARD

Organized a **Seminar on Astrophysics and Nuclear-Astrophysics** on **December 24, 2024, from 2.00 PM onwards** at the Seminar Room, Department of Physics, Aliah University, New Town campus. The following lectures were delivered:

Lecture 1:

Interesting features of radiating stellar structures.
Professor (Dr.) Sunil Maharaj,
(Astrophysics Research Centre, School of Mathematics, Statistics and Computer Science, University of KwaZulu-Natal, Durban, South Africa).

Lecture 2:

Nuclear Reactions in s-process nucleosynthesis.
Professor (Dr.) Gautam Gangopadhyay
(Dept. of Physics, Calcutta University, India)

Visitors at ICARD, Aliah University:

1. **Dr. Rajibul Shaikh,** Senior Researcher, Seoul National University of Science and Technology, Seoul, South Korea visited ICARD, Dept. of Physics, Aliah University during January 27-29, 2025 for some scientific discussion and possible research collaboration afterwards. The topic of the discussion mainly on "**Black Hole Mimickers and Their Observational Aspects, including Shadows and Images"**.

2. **Prof. Bikash Ch. Paul,** Professor, Dept. of Physics, University of North Bengal visited ICARD, Dept. of Physics, Aliah University during January 31- Feb. 05, 2025 for scientific research and collaboration.

Publications by using ICARD facilities:

Members of ICARD, Aliah University have published articles in the following journals:

[1] Thin shell wormhole from rotating hairy black hole in (2+ 1)-dimensions. F Rahaman, N Rahman, **M Kalam**, M Murshid, A Das, S Islam, S Das. **The General Relativity and Gravitation 57 (2), 40 (2025). DOI:** https://doi.org/10.1007/s10714-025-03371-8

[2] Analytical model of low-mass strange stars using Tolman space-time in (2+1) dimensions. T Kundu, M Murshid, PK Haldar, **M Kalam. Pramana 98 (2), 75 (2024). DOI:** https://doi.org/10.1007/s12043-024-02741-2

[3] Wormholes in dwarf and spiral galactic halo regions. **M Kalam**, A Ghari, I Radinschi, H Haghi, F Rahaman, T Chowdhury. **New Astronomy 113, 102288 (2024). DOI:** https://doi.org/10.1016/j.newast.2024.102288

[4] Gravastar in the framework of Loop Quantum Cosmology. Shounak Ghosh, Rikpratik Sengupta and **Mehedi Kalam** . **The European Physical Journal Plus 139 (6), 465 (2024) DOI:** https://doi.org/10.1140/epjp/s13360-024-05264-2

[5] Neutron stars in f (R, T) theory: slow rotation approximation. Masum Murshid and **Mehedi Kalam. Journal of Cosmology and Astroparticle Physics 2024 (09), 030 (2024) DOI:** https://doi.org/10.1088/1475-7516/2024/09/030

ICARD at Relativity and Cosmology Research Centre, Department of Physics, Jadavpur University, Kolkata

ICARD Coordinator:
Avijit Mukherjee and Soumen Mondal

Areas of research

The research activities at the center encompass a wide array of topics in theoretical physics and astrophysics, with an emphasis on both foundational and cutting-edge areas. The faculty members and PhD scholars are actively engaged in the following major research domains:

General Relativity and Cosmology, Quantum Field Theory in Curved Spacetimes and Quantum Cosmology, 21-cm Cosmology, Mathematical Aspects of Quantum Field Theory and Gauge Theory, String Theory, Gravitational Waves and Compact Objects, Accretion Physics around Rotating Black Holes.

Research work done in ICARD

Researchers at the center have made significant contributions in two cutting-edge areas of theoretical and observational cosmology. On the theoretical front, they studied a massless, minimally coupled self-interacting quantum scalar field in de Sitter inflationary spacetime, with a hybrid potential incorporating both quartic and cubic terms. By constructing and analysing the Schwinger-Dyson equation up to two-loop order, they demonstrated the generation of a dynamical mass via non-perturbative resummation of secular logarithms, highlighting the limitations of one-loop approximations in the presence of cubic interactions. In parallel, in the realm of observational cosmology, they explored the feasibility of detecting ionized bubbles during the Epoch of Reionization through redshifted 21-cm signals using the uGMRT and SKA1-Low. Through detailed simulations and matched filter techniques, they demonstrated the detectability of these bubbles with high statistical significance, offering a promising pathway to constrain the properties of early luminous sources and the surrounding intergalactic medium.

Workshops/Schools Organised by ICARD

One-day Conference on **Recent trends of Gravitation and Cosmology,** Relativity and Cosmology Research Center, Department of Physics, Jadavpur University, Kolkata-700032 on 18th March 18, 2025.

Publications by using ICARD facilities:

1. Resummation of local and non-local scalar self-energies via the Schwinger-Dyson equation in de Sitter spacetime, Gen. Rel. Grav 56 (2024) 8.

2. Detecting ionized bubbles around luminous sources during the reionization era using HI 21-cm signal, JCAP 02 (2025) 055.

ICARD-Department of Physics, Malda College, Malda, West Bengal

ICARD Coordinator:
Dr Shyam Das

Areas of Research

Research focuses on Relativistic Astrophysics and the theoretical modeling of compact stellar objects, focusing on gravitational collapse, gravitational tidal effects, complexity and their astrophysical implications. It also investigates modified theories of gravity, such as f(R), f(Q), f(R,T), and f(Q,T) gravity, to deepen our understanding of spacetime, cosmic evolution, and the fundamental nature of gravity.

Research Work

ICARD, Malda College is a newly established centre sponsored by IUCAA, Pune started its activity from Nov 1, 2024. Researchers at ICARD, Malda College are actively engaged in the theoretical modeling of compact astrophysical objects, such as neutron stars and wormholes, validating their models with observational data. Shreya Majumder, a research scholar under Dr. Shyam Das, is working jointly with Prof. Farook Rahaman (Jadavpur University) on compact stellar structures. Lipi Baskey has successfully earned her Ph.D. under the joint supervision of Malda College and Jadavpur University, focusing on various aspects of compact stars.

In collaboration with esteemed researchers like Prof. Megandhren Govender (South Africa), Prof. Bikash Chandra Paul (North Bengal University), and Prof. Farook Rahaman (Jadavpur University), Dr Ranjan Sharma (CBPBU) the team is exploring stellar properties and the modeling of compact objects within General Relativity and modified theories of gravity. These collaborative efforts have led to significant research publications, contributing to advancements in astrophysical studies.

Workshop/Schools organized

Inauguration of ICARD: The IUCAA Centre for Astronomy Research and Development (ICARD) at Malda College, under the

Department of Physics, was inaugurated on January 28, 2025, by Prof. Sauren Bandopadhaya, President of the Governing Body, Malda College, and Vice-Chancellor of WB State University.

A special lecture "*The Amazing Universe*", jointly organized by ICARD, Department of Physics, Malda College, and Paschim Banga Vigyan Mancha, Malda Branch, held on February 6, 2025, at Malda College.

National Science Day Celebrations: A one-day seminar on the theme "Empowering Indian Youth for Global Leadership in Science & Innovation for Viksit Bharat" organized by ICARD and the Department of Physics on The National Science Day, February 28, 2025 at Malda College.

Outreach Programmes, including public lectures/sky watch

1. Night Sky Watch Program at Malda College organised by ICARD, Malda College, in collaboration with IASES faculty, organized a Night Sky Watching Program for students, offering them a hands-on experience in astronomical observation on 28th February 2025.
2. Public lecture on the Solar System and Wonders of Universe organised by ICARD, Malda College, in collaboration with NSS, Malda College conducted an engaging outreach session on 19th March 2025 in a rural village (Nariyali Gram) of Malda.
3. The Night Sky Observation event, organized by ICARD, Malda College in collaboration with Paschim Banga Vigyan Mancha, Malda Branch, organised on March 21, 2025, at 6:00 PM at Paschim Banga Vigyan Mancha Office, Atul Market.

Publications using ICARD facilities:

1. Exploring anisotropic compact stellar models under the Condition of zero Complexity, **Shyam Das,** Saibal Ra, Amit Das, S. K. Pal, New Astronomy, **119**, 102393, (2025).
2. Exploring complexity in the presence of anisotropic stresses and density inhomogeneities for compact objects**, Shyam Das,** Megandhren Govender, Lipi Baskey, EPJC, **85**, 232, (2025).
3. Thin shell wormhole from rotating hairy black hole in (2+1)-dimensions, Farook Rahama, N Rahman, M Kalam, M Murshid, A. Das, S. Islam, **Shyam Das,** GRG, **57**, 40, (2025).
4. Anisotropic compact stellar object under quasi local EOS, **Shyam Das**, Bikash Chandra Paul, Iftikar Hossain, Shyamal Kr Pal, EPJC, **85**, 275, (2025).
5. Complexity Characterization in modeling Anisotropic Compact Stellar Structures, **Shyam Das,** Megandhren, Somi Aktar, EPJC, **84**, 1112, (2024).
6. The Influence of Spheroidicity on the Complexity in Compact Objects Utilizing the Vaidya–Tikekar Superdense Star Model, Shyamal Kr Pal**, Shyam Das,** Ankita Jangid, Brazilian J. of Physics, **55**, 30, (2024).

Department of Physics, Visva-Bharati, Santiniketan, West Bengal

ICARD Coordinator:
Dr. Sudipta Das

Areas of research

General Relativity, Cosmology, Dark Energy, Modified Theories of Gravity, Large-scale structures in the Universe, Galaxy formation and evolution, X-ray Astronomy, Theoretical aspects of gravitational physics

Brief report about the research work done in ICARD:

In the field of Cosmology, one of the primary research interest is to understand the accelerated expansion of the Universe by looking into various aspects of dark energy models. Barrow holographic dark energy model is an extension of holographic dark energy that incorporates modifications to entropy due to quantum gravitational effects. The cosmological properties of interacting Barrow holographic dark energy model in the case of non-zero curvature universe has been explored. The differential equations governing the evolution of the Barrow holographic dark energy density parameter and the dark matter density parameter in coupled form has been constructed for both closed and open spatial geometry. Considering three different forms of coupling, the corresponding analytical expressions for the equation of state parameter for the dark energy component has been obtained. The scenario is confronted using recent observational datasets like cosmic chronometer and Pantheon data. It has been found that the strength of interaction as well as the curvature contribution come out to be nonzero which indicates that a non-flat interacting scenario is preferred by observational data.

Apart from this, research work has been carried out to understand the large scale structure of the universe. In this regard, studies have been carried out to test the statistical homogeneity and isotropy of the Universe on large scales. Studies have been carried out to understand the roles of large-scale environment on galaxy formation and evolution and also to quantify the topology and morphology of large scale structures in the Universe. Applications of information theory and fuzzy set theory in different areas of Cosmology has also been explored.

In the field of X-ray astronomy, the spectral and timing analysis of different neutron star low-mass X-ray binaries (LMXBs) have been performed using the latest NICER and NuSTAR observations. All the sources were transient; some exhibited pulsing behavior, which were later identified as millisecond X-ray pulsars. The primary focus was to study the reflection component and put constraints on the inner disk parameters. For that the high-quality NuSTAR spectra has been used to study different spectral signatures. The accretion geometry of the system was correctly constrained by modeling the reflection spectrum using NuSTAR data because of its unprecedented sensitivity above 10 keV. Moreover, fitting with self-consistent reflection models provided essential insights, including the position of the magnetospheric radius and the neutron star magnetic field. Some theoretical aspects of gravitational physics have also been explored in some other works.

List any colloquia/Seminars organised by ICARD

Activities from 1st November, 2024 to 31st March, 2025

Colloquium lecture delivered by Dr. Soumavo Ghosh, IIT – Indore on Monday, December 09, 2024 at 4.30 p.m. at the Auditorium, Department of Physics, Visva-Bharati

Title of talk: Unveiling the mysteries of our own Milky Way with the Gaia space mission.

Colloquium lecture delivered by Dr. Trisha Bhowmik, Universidad Diego Portales, Santiago, Chile. On Friday, February 21, 2025 at 4.30 p.m. at the Auditorium, Department of Physics, Visva-Bharati.

List of publications by using ICARD facilities:

Publications from 1st November, 2024 to 31st March, 2025

i. Interacting Barrow holographic dark energy in non-flat universe by Priyanka Adhikary and Sudipta Das, Journal of Cosmology and Astroparticle Physics, 2025 (in press).

ii. NuSTAR view of the X-ray transients Swift J174805.3-244637 and IGR J17511-3057 by Aditya S. Mondal, Mahasweta Bhattacharya, Mayukh Pahari, B. Raychaydhuri, Rohit Ghosh,

iii. G. C. Dewangan Journal of High Energy Astrophysics, **45**, 359 (2025).

iv. Tachyonic field coupled with global monopole by B. Samanta, B. Raychaudhuri, F. Rahaman, Aditya S. Mondal, and S. Sarkar International Journal of Theoretical Physics, **63**, 297 (2024).

v. Unveiling galaxy pair alignment in cosmic filaments: A 3D exploration using EAGLE simulation by Suman

Sarkar and Biswajit Pandey, Journal of Cosmology and Astroparticle Physics, **01**, 023 [2025]

vi. The size and shape dependence of the SDSS galaxy bispectrum by Anindita Nandi, Sukhdeep Singh Gill, Debanjan Sarkar, Abinash Kumar Shaw, Biswajit Pandey, Somnath Bharadwaj

vii. Somnath Bharadwaj, New Astronomy, **113**, 102292 [2024]

Outreach program (including public lectures / sky watch) organised by ICARD

Activities from 1st November, 2024 to 31st March, 2025

(I) A science exhibition was organized at the Department of Physics on the occasion of National Science day on February 28, 2025. Many school children from nearby schools visited the department on this occasion.

Sky watching session organized on January 28 - 29, 2025 at 5.30 pm to watch the planetary parade.

Department of Physics, North Bengal University Darjeeling, Siliguri West Bengal

ICARD Coordinator:
Professor B. C. Paul

Research Area

Relativistic Astrophysics, Cosmology, Compact Objects, DATA analysis of X-ray Sources,
Non-linear Dynamics.

Activities of the DATA Centre

A group of four students one Post Doc and other three SRF are engaged to analyse the X-ray Pulsar DATA archived in the NASA website. The group is constantly vigil the new results in X-ray pulsars and a number of papers published reporting our findings.

2.1. Anisotropic Universe with Barrow Holographic Dark Energy Research Scholars are engaged to Analyse X-ray Data of NASA to investigate Different X-ray Emitting Pulsars. At present four Research Scholars are engaged in doing research using the facilities of the ICARD DATA Centre. It is proposed to use ASTROSAT-data from IUCAA soon.

PUBLICATIONS BY IUCAA MEMBERS

a) Journals

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Conference Paper

1. Simran Arora, Monal Kashav, Surender Verma, **B.C. Chauhan** (2024) *Muon Anomalous Magnetic Moment and Neutrino Mass in U(1)Lμ−Lτ Extended Scotogenic Model,* –**Proceedings of the XXV DAE-BRNS High Energy Physics (HEP) Symposium 2022, 1216 December, Mohali, India**, **304**, 713-715, Jul 17, 2024, https://doi.org/10.1007/978-981-97-0289-3_171.

2. Ankush, R. Verma, and **B. C. Chauhan**, "Scotogenic Bounds on Dirac CP Phase Consistent with Neutrino less Double Beta Decay in Hybrid Texture of Neutrino Mass Matrix, –**Proceedings of the XXV DAE-BRNS High Energy Physics (HEP) Symposium 2022, 1216 December, Mohali, India** 304 (2024) 834-836, Jul 17, 2024, https://doi.org/10.1007/978-981-97-0289-3_211.

3. R. Verma, Ankush, **B. C. Chauhan**(2024) *Electron and Muon (g−2)e,μ⊗ Anomalous Magnetic Moment in U(1)Le−Lμ⊗ Symmetry Model,* –**Proceedings of the XXV DAE-BRNS High Energy Physics (HEP) Symposium 2022, 1216 December, Mohali, India**, **304**, 1300-1302, Jul 17, 2024, **https://doi.org/10.1007/978-981-97-0289-3_371**.

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Circular

1. N. Poloji, **P. Hasan**, and S. N. Hasan (2024) *VizieR Online Data Catalog: Coma cluster core's galaxies morphology study (Poloji+, 2022)*, VizieR Online Data Catalog, **751**, Art. no. J/MNRAS/510/4463, 2024. J/MNRAS/510/4463.

2. S. N. Hasan, and P. Shah (2024) *Dynamics of Mass Segregation in Open Star Clusters.*, IAUGA, Art. no. **345**. **IAU General Assembly**

3. **S. N. Hasan,** and P. Shah (2024) *A Detailed Study of Dwarf Galaxies in the Core of the Coma Cluster*, IAUGA, Art. no. **344**. **IAU General Assembly**

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6. **S. N. Hasan,** and P. Shah (2024) *Exploring the collinear Lagrangian points of exoplanet systems with P-R drag andoblateness*, IAUGA, Art. no. **328**. **IAU General Assembly**

7. P. Shah, and **S. N. Hasan (2024)** *VO Tools and Data Analysis for Copperbelt University, Zambia: VO-OAD Special Grant: Execution, Methodology, Lessons learned*, IAUGA, Art. no. **324**. **IAU General Assembly**

8. P. Shah (2024) *An update on the satellite interference to dark skies*, IAUGA, Art. no. **323**. **IAU General Assembly**

9. P. Shah, and **S. N. Hasan** (2024) *Mass segregation in the Gaia Era*, IAUGA, Art. no. **322**. **IAU General Assembly**

10. P. Shah (2024) *Gaps in the Main Sequence of Star Clusters with Gaia DR3 data*, IAUGA, Art. no. **321**. **IAU General Assembly**

11. P. Shah (2024) *Star cluster membership with DBSCAN*, IAUGA, Art. no. **320**. **IAU General Assembly**

12. P. Shah (2024) *Three years of Astronomy writing in Chekhumukhi: A newsletter by JVV, Telangana, India*, IAUGA, Art. no. **319**. **IAU General Assembly**

13. P. Shah, and **S. N. Hasan (2024)** *LCO remote telescopes as an Educational Tool in the study of star clusters*, Art. no. **318**. **IAU General Assembly**

Book

B. C. Chauhan

1. Authored Chapter '*IKS: In the Roots of Modern Science* ' Vedic Science 24 (2024) 7 (2024); ISSN 0975-0312.

2. Authored Chapter '*History and Culture of Science in Bharata*' Vol.-I, p460, Garuda Prakashan, ISBN 979-8-8857-5151-3.

3. Authored Chapter '*History and Culture of Science in Bharata*' Vol. II, p484, Garuda Prakashan, ISBN 979-8-8857-5155-1.

4. Authored Chapter *'IKS or Maharshi Vyas ki Tapobhumi Himachal'* Proceedings of National Seminar on 'Contributions of Himachal in IKS', Sanskrit Central Univ. Dehra, 19-20th Oct. 2025.

S. N. Hasan

1. Authored Chapter '*Astronomy Olympiads: Problems with Solutions*' *by* Prof Vladimir G. Surdin (Author), Margarita Safonova (Translator), Priya Hasan (Translator), **S. N. Hasan** (Translator) OrangeBooks Publication; 1st edition (6 April 2023), ISBN-10: 9356216711, ISBN-13: 978-9356216716

2. Authored Chapter **'***Algebraic and Quantum Mechanical Approach to Spinors Mathematical Methods for Engineering Applications*' Springer Proceedings in Mathematical Methods for Engineering Applications, **439**, Springer Nature Switzerland.

P. K. Sahu

1. Authored Chapter '**A New Way to Construct Wormholes in Modified Gravity**' Current Perspective to Physical Science Research, **8**, p. 32-44. B P International, ISBN 978-81-971665-1-8

Biplob Sarkar

1. Authored Chapter '*Accretion Disc Outbursts and Stability Analysis*' pp 8-11, Book title: Physics Frontiers: Bridging Theories and Experiments (Volume-I) edited by Dr. Darpan Bhattacharjee and Dr. Vivek Baruah Thapa, Published by- Assam Science Society in Collaboration with Research & Development Cell, Bhawanipur Anchalik College, Barpeta, Assam - 781352, India, ISBN: 978-81-983738-4-7, Edition: 2025, **https://doi.org/10.5281/zenodo.14626413**

2. Authored Chapter 'An *Overview of Numerical Simulations in Accretion Physics*' pp 12-17, Book title: Physics Frontiers: Bridging Theories and Experiments (Volume-I) edited by Dr. Darpan Bhattacharjee and Dr. Vivek Baruah Thapa, Published by- Assam Science Society in Collaboration with Research & Development Cell, Bhawanipur Anchalik College, Barpeta, Assam - 781352, India, ISBN: 978-81-983738-4-7, Edition: 2025, **https://doi.org/10.5281/zenodo.14626413**

3. Authored Chapter '*Spectro-temporal study of atoll source GX 9+9 observed with AstroSat*' pp 18-22, Book title: Physics Frontiers: Bridging Theories and Experiments (Volume-I) edited by Dr. Darpan Bhattacharjee and Dr. Vivek Baruah Thapa, Published by- Assam Science Society In collaboration with Research & Development Cell, Bhawanipur Anchalik College, Barpeta, Assam- 781352, India, ISBN: 978-81-983738-4-7, Edition: 2025, **https://doi.org/10.5281/zenodo.14626413**

4. Authored Chapter '*Relativistic Accretors and High Energy X-Ray view*' pp 33-40, Book title: Physics Frontiers: Bridging Theories and Experiments (Volume-I) edited by Dr. Darpan Bhattacharjee and Dr. Vivek Baruah Thapa, Published by- Assam Science Society In collaboration with Research & Development Cell, Bhawanipur Anchalik College, Barpeta, Assam - 781352, India, ISBN: 978-81-983738-4-7, Edition: 2025, **https://doi.org/10.5281/zenodo.14626413**

The Bombay Public Trust Act, 1950

SCHEDULE - VIII
[Vide Rule 17 (1)]

Name of the Public Trust : Inter-University Centre for Astronomy and Astrophysics — Registration No. : F-5366
Balance Sheet As At : 31.03.2025 — Dated : 27.01.1989

FUNDS & LIABILITIES	Sch NO.	Rs.	Current year 01.04.2024 to 31.03.2025 Rs	Previous year 01.04.2023 to 31.03.2024 Rs	PROPERTY & ASSETS	Sch NO.	Rs.	Current year 01.04.2024 to 31.03.2025 Rs	Previous year 01.04.2023 to 31.03.2024 Rs
Trusts Funds or Corpus :-	6				**Immovable Properties :- (At Cost)**	11			
Balance as per last Balance Sheet		2,67,75,567			Balance as per last Balance Sheet		71,20,07,125		
Adjustment during the year (give details)		16,30,055			Additions during the year		19,09,95,458		
Schedule No. 6			**2,84,05,622**	**2,67,75,567**	Less : Sales /written off during the year				
Other Earmarked Funds :-	7				Depreciation up to date		13,21,03,184		
(Created under the provisions of the trust deed or scheme or out of the Income)			**13,18,25,389**	**12,25,95,552**	**Schedule No. 11**			**77,08,99,399**	**71,20,07,125**
					Investments :-	12			
Balance as per last Balance Sheet		Opening Balance			Note : The market value of the above				
Grant in Aid - 2 MTR (CAPITAL)			**11,90,80,000**	**11,90,80,000**	investment is Rs.				
Grant in Aid BUILDING			**11,97,49,000**	**11,97,49,000**	**Schedule No. 12**			**50,37,07,722**	**47,81,33,500**
Capital Grant to the Extent of Depriciation		1,91,85,18,956			Furniture & Fixtures :-	11		**1,43,65,318**	**1,84,46,643**
Additions during the year		(7,50,00,010)	**(1,99,35,18,966)**	**(1,91,85,18,956)**	Balance as per last Balance Sheet		1,84,46,643		
					Additions during the year		2,86,873		
Grant in Aid General (Capital) from UGC		2,75,01,74,979			Less : Sales /written off during the year				
Additions during the year		22,20,00,000			Depreciation up to date		43,68,198		
Add: Interest		4,90,040							
Less : Subtraction/reversed		(3,34,60,000)			**Schedule No. 11**				
Schedule No. 7			**2,93,92,05,019**		**Loans (Secured or Unsecured) :**				
				2,75,01,74,979	**Good/doubtful**				
Any Other Fund - Project Grants	8				Loans Scholarships				NIL
Schedule No. 8			**31,53,52,667**	**36,99,34,793**	Other Loans				NIL
					Advances :-	13			
Loans (Secured or Unsecured) :-					To Trustees				NIL
From Trustees				**NIL**	To Employees and other			**2,92,23,767**	**1,36,90,907**
From Others				**NIL**	To Suppliers/Security Deposits/Prepaid Exp.			**2,36,58,675**	**2,27,96,595**
Liabilities :-	10&10A				To Lawyers				NIL
For Expenses and other liabilities			**32,06,94,967**	**26,07,52,379**	To Project and Other Receivables			**13,16,685**	**12,02,633**
For Projects and Other Payables			**7,36,05,554**	**7,22,57,553**	**Schedule no. 13 & 13A**				
For Rent & Other Deposits, duties and taxes			**2,36,27,630**	**1,15,937**					
For Sundry Credit Balances			**2,02,427**	**35,634**	**Income Outstanding :-**				
Schedule No. 10 &10 A					Rent				
					Interest				
Income and Expenditure Account :-	14				Other Income				
Balance as per last Balance Sheet		(46,29,99,865)							
Less : Appropriation, if any		(49,79,522)			**Cash and Bank Balances :-**	13			
					(a) In Savings Account with -				
Add : Deficit during the year		(2,70,70,165)			Bank of Baroda				
Less : Surplus			**(49,50,49,552)**		In Fixed Deposit Account with -				
Schedule No. 14				**(46,29,99,865)**					
					(b) With the Trustee				
					(c) With the Manager				
					Schedule no. 13 B			**24,00,08,190**	**21,36,75,171**
TOTAL			**1,58,31,79,756**	**1,45,99,52,573**	**TOTAL**			**1,58,31,79,756**	**1,45,99,52,573**

As per our report of even date,

For Kirtane & Pandit LLP
Chartered Accountants
Firm Registration No.105215W/W100057

KIRTANE & PANDIT LLP * Chartered Accountants * FRN 105215W/W100057

Parag Pansare
(Partner)
Membership No. 117309

Place : Pune
Dated : 16.06.2025

M.S. Sahasrabudhe
Admin. Officer (Accounts)

The above Balance Sheet to the best of my/our belief contains a true account of the Funds and Liabilities and of the Property and Assets of the Trust.

For Inter-University Centre for Astronomy and Astrophysics

Cdr V K Vijay Balaji (Retd.)
Sr. Admin. Officer

Prof. R. Srianand
Director / Trustee

Chairperson/Trustee
Governing Board

**This Balance Sheet is as per BPT Format and Charity Commissioner's Instructions

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IUCAA

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