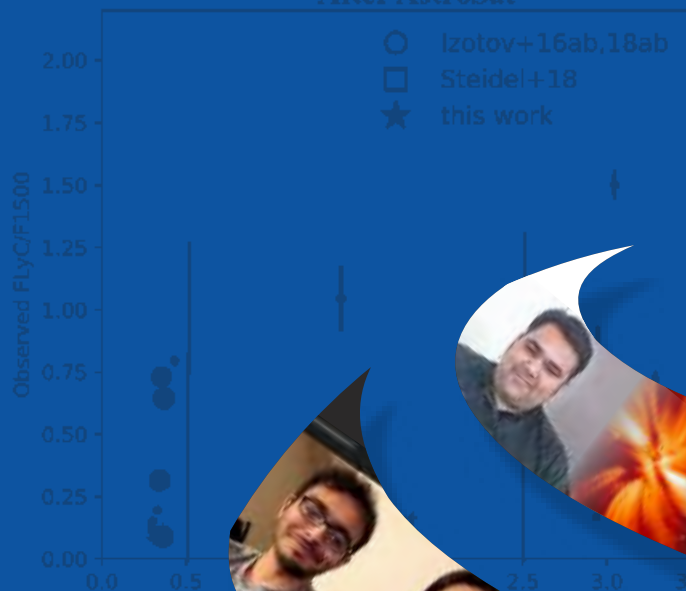
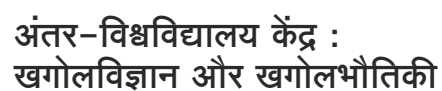


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33rd
ANNUAL REPORT
2020-21



अंतर-विश्वविद्यालय केंद्र :
खगोलविज्ञान और खगोलभौतिकी

**INTER-UNIVERSITY CENTRE FOR
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153. Somasri Sen, Department of Physics, Jamia Millia Islamia, New Delhi.
154. Anand Sengupta, Department of Physics, IIT, Gandhinagar.
155. T.R. Seshadri, Department of Physics and Astrophysics, University of Delhi.
156. Ranjan Sharma, Department of Physics, Cooch Behar Panchanan Barma University.
157. Umesh K. Sharma, Department of Mathematics, GLA University, Mathura.
158. Alkendra Singh, Department of Physics, Institute of Science, Banaras Hindu University, Varanasi.
159. Gyan P. Singh, Department of Mathematics, Visvesvaraya National Institute of Technology, Nagpur.
160. Harinder P. Singh, Department of Physics and Astrophysics, University of Delhi.
161. Heisnam S. Singh, Department of Physics, Rajiv Gandhi University, Itanagar.
162. Monika Sinha, Department of Physics, IIT, Jodhpur.
163. Surendra N. Somala, Department of Civil Engineering, IIT, Hyderabad.
164. Vikram Soni, Centre for Theoretical Physics, Jamia Millia Islamia, New Delhi.
165. K. Sriram, Department of Astronomy, University College of Science, Osmania University, Hyderabad.
166. L. Sriramkumar, Department of Physics, IIT – Madras, Chennai.
167. Parijat Thakur, Department of Basic Sciences and Humanities, Guru Ghasidas Central University, Bilaspur.
168. Arun V. Thampan, Department of Physics, St. Joseph's College, Bengaluru.
169. Sunil K. Tripathy, Department of Physics, Indira Gandhi Institute of Technology, Dhenkanal.
170. Pranjal Trivedi, Department of Physics, Sri Venkateswara College, Delhi.
171. Vinutha Tummala, Department of Applied Mathematics, Andhra University, Visakhapatnam.
172. Rashmi Uniyal, Department of Physics, Government Degree College, Narendranagar,
173. Sanil Unnikrishnan, Department of Physics, St. Stephen's College, Delhi.
174. Sudhaker Upadhyay, Department of Physics, KLS College, Nawada.
175. Anisul A. Usmani, Department of Physics, Aligarh Muslim University.
176. Nilkanth D. Vagshette, Department of Physics and Electronics, Maharashtra Udaygiri Mahavidyalaya, Udgir.
177. Deepak Vaid, Department of Physics, NIT, Surathkal.
178. Bhargav P. Vaidya, Discipline of Astronomy, Astrophysics and Space Engineering, IIT, Indore.
179. Murlu M. Verma, Department of Physics, University of Lucknow.
180. Jaswant K. Yadav, Department of Physics, Central University of Haryana, Mahendergarh.
181. Lalthakimi Zadeng, Department of Physics, Mizoram University, Aizawl.



The Thirty–First batch (2020) of Visiting Associates, who were selected for a tenure of three years, beginning, August 1, 2020.



**PRIYA
BHARALI**



**RASHMI
BHARDWAJ**



**SRIJIT
BHATTACHARJEE**



**SUBHRA
BHATTACHARYA**



**HUM
CHAND**



**RAKA VASANT
DABHADE**



**SHYAM
DAS**



**ABHIK
GHOSH**



**M.
HONEY**



**R.K. SUNIL
KUMAR**



**S. SUNIL
KUMAR**



**SANJAY
KUMAR**



**LITON
MAJUMDAR**



**RAM AJOR
MAURYA**



**K. SATHYA
NARAYANAN**



**R.
RAKHI**



**GAURANGA
CHARAN SAMANTA**



**UMESH KUMAR
SHARMA**

Appointment of the following Visiting Associates of the Twenty-Eighth batch was extended for three years from August 2020: Bijan K. Bagchi, Arunima Banerjee, Sarmistha Banik, Naseer I. Bhat, Nand K. Chakradhari, Ramesh Chandra, Suresh Chandra, Ayan Chatterjee, Ritaban Chatterjee, Suchetana Chatterjee, Surajit Chattopadhyay, Asis K. Chattopadhyay, Tanuka Chattopadhyay, Sudipta Das, Ujjal Debnath, Shantanu Desai, Dhurjati P. Datta, Gaurav Goswami, Nandita Kalita, Arun V. Kulkarni, Suresh Kumar, Smriti Mahajan, Manzoor A. Malik, Soma Mandal, Titus Mathew, Irom A. Meitei, Hameeda Mir, Saptarshi Mondal, Pradip Mukherjee, Dibyendu Nandi, Mahadev B. Pandge, Kishor D. Patil, Surajit Paul, Ninan S. Philip, Shantanu Rastogi, Saibal Ray, Prabir Rudra, Saumyadip Samui, Anand Sengupta, T. R. Seshadri, Heisnam S. Singh, Gyan P. Singh, Monika Sinha, Vikram Soni, K. Sriram, Arun Thampan, Sunil K. Tripathy, Vinutha Tummala, Rashmi Uniyal, and Deepak Vaid.



ORGANIZATIONAL STRUCTURE OF ACADEMIC PROGRAMMES



33rd
ANNUAL REPORT
2020-21

(As on March 31, 2021)



The Director
Somak Raychadhury



**Dean,
Core Academic Programmes**
Dipankar Bhattacharya



**Dean,
Visitor Academic Programmes**
Kandaswamy Subramanian



Dipankar Bhattacharya,
Head, Computing Facilities



R. Srianand,
Head, Observing Programmes
(at IGO and SALT)



Aseem Paranjape,
Head, Publications



Ranjeev Misra,
Head, Scientific Meetings



A.N. Ramaprakash,
Head, Instrumentation



Ranjeev Misra,
Head, ICARDs



Gulab Dewangan,
Head, Teaching Programmes



Surhud More,
Head, Public Outreach Programmes



Durgesh Tripathi,
Head, Library



Somak Raychaudhury,
Head Infrastructural Facilities



Kandaswamy Subramanian,
Head, Grievance Cell



DIRECTOR'S REPORT



33rd
ANNUAL REPORT
2020-21

Since its inception more than three decades ago, one of the main objectives of IUCAA has been to become and remain a Centre of Excellence in research and training within the family of Indian Universities, and to conduct a, internationally reputed vigorous research programme of its own in Astronomy and Astrophysics and related subjects (A&A). IUCAA was set up to promote nucleation and growth of active groups in A&A in Indian Universities and Colleges, and to function as a field station and resource centre to provide general guidance and help for A&A activities in India and neighbouring countries. IUCAA has always put in the best effort to achieve these objectives, and has maintained the emphasis on fundamental research and innovative teaching in almost all areas of A&A. A new crop of IUCAA Centres for Astronomy Research and Development (ICARDs) have been set up all through the country, to enhance teaching and research in Indian Universities/ Colleges.

Over the last decade, IUCAA has assumed a leading role in large projects of national importance, including LIGO-India, the Thirty Metre Telescope, and is a significant contributing partner in the Square Kilometre Array and various space projects of ISRO, including AstroSat, and Aditya-L1, whose launch is imminent. The AstroSat Science Support Cell has been functioning very well with financial support from ISRO, through which members of IUCAA and substantial number of Visiting Associates and their students could collect data and analyse, and publish quite a number of research papers.



IUCAA, together with the Savitribai Phule Pune University, is about to start an MSc in Physics with Astrophysics degree course from the coming academic year. During this year, a Precision and Quantum Measurement laboratory has been established in IUCAA, as a part of the DST's nationwide Quantum initiative QUEST, where state-of-the-art experimental facilities based on trapped and laser cooled single ytterbium ion ($^{171}\text{Yb}^+$) confined in an electrodynamic trap will be developed. This facility offers to build one of the most sensitive optical atomic clocks at 467 nm wavelength, and will also aid the training of various young researchers for laser-related activities for LIGO-India.

IUCAA currently has 27 Core Faculty and Emeritus Professors, 38 Post-Doctoral Fellows, and 60 PhD Scholars. They have collectively published 153 peer-reviewed papers, with a mean impact factor of 5.79. We are very proud of this, since it shows that our colleagues are not just very productive in research of the highest quality, but they are making a substantial impact on the subject at the national and international levels. Even more gratifying is the fact that the 181 Visiting Associates of IUCAA, who are faculty members at Indian Universities and Colleges, supported in their research by IUCAA, have published 416 peer-reviewed papers during the same period, with a mean impact factor of 4.21. This number has increased over the years, and clearly indicates the impact IUCAA has had in promoting and nurturing A&A research at institutions of higher education all over the country, and has provided facilities and the right atmosphere for nurturing active collaboration between members of the community of associates and the national and international communities. However, during this year, the Visitor Programmes were cancelled due to the pandemic situation in the country. During this year, three IUCAA students have obtained their PhD degree, which is lower than usual because of the pandemic restrictions.

During this year, we welcomed one new member to our Core Faculty, Sowgat Muzahid, who has joined us from Leiden Observatory, Netherlands. He has been an active member of the Multi-Unit Spectroscopic Explorer (MUSE) consortium. His primary focus on research is to understand the role of diffused gas in the formation and evolution of galaxies using ultraviolet/optical spectroscopy. Varun Sahni, one of our most valued senior core faculty members, has superannuated in March 2021, and has been offered Emeritus Professorship. With deep sorrow and sadness, I would like to mention the demise of Dr Srikumar Banerjee, who was the Chairman of our Governing Board for two terms, and Professor S.M. Chitre, Professor Arun Nigavekar, and Professor Govind Swarup, who were the mentors and pillars of IUCAA for a long time. Along with the IUCAA



family, I express our heartfelt condolences to the bereaved family and friends. They all will be remembered in the history of IUCAA.

The 32nd Foundation Day Lecture was delivered on Tuesday, December 29, 2020, by Professor Raghavendra Gadagkar, DST Year of Science Chair Professor at the Centre for Ecological Sciences, Indian Institute of Science, Bengaluru. Due to the ongoing restrictions, the lecture was held entirely online, with a live YouTube stream that drew hundreds of viewers as well as a smaller, interactive audience on Zoom. Professor Gadagkar is an expert on Animal Behaviour, Ecology and Evolution, with more than three decades of experience focusing primarily on the origin and evolution of cooperation in animals, especially in social insects, such as ants, bees and wasps. In his lecture, titled 'War and Peace: Conflict and Cooperation in an Insect Society', Professor Gadagkar presented examples of observations and experiments attempting to understand the workings of a particular tropical insect society, the Indian paper wasp '*Ropalidia marginata*'. The recorded lecture is available at the YouTube link: <https://www.youtube.com/watch?v=sHI0-xuQTc8>.

Among the members of IUCAA, **Sanjeev V. Dhurandhar** has been elected Fellow of the American Physical Society, for foundational contributions to the theoretical underpinnings of gravitational wave detection, especially in data analysis techniques, and for the development of India's gravitational wave community leading to LIGO – India. **Samir Dhurde** (shared with Vivek Monteiro) has been presented the Zubin Kambhavi Award by the Astronomical Society of India, for the public outreach and education in astronomy and allied fields. **Neeraj Gupta** (and team) has been given the AAAS Newcomb Cleveland Prize, for the research paper: *A single fast radio burst localized to a massive galaxy at cosmological distance*. **Jayant V. Narlikar** has been selected as the President of the 94th Akhil Bharatiya Marathi Sahitya Sammelan (94th All India Marathi Literary Meet), and presented the Krishnaji Medal (Lecture Award), by the National Academy of Sciences, India. **T. Padmanabhan** has been given the Fifth Prize in the Gravity Research Foundation Essay Contest for: *Principle of equivalence at Planck scales and the zero-point length of spacetime: A synergistic description of quantum matter and geometry*. **Kanak Saha**, and **Shyam N. Tandon** (and team) have been bestowed the New Discovery Award, by the Astronomical Society of India, for their work on detection of Lyman continuum emission from a $z = 1.42$ galaxy using AstroSat.

Funded by the Ministry of Human Resources Development, Government of India, under the Pandit Madan Mohan Malaviya National Mission on Teachers and Teaching Scheme, the Astronomy Centre for Educators, consisting of the National Resource Centre for A&A, and the Teacher Learning Centre, hosted at IUCAA, have developed online A&A courses for Annual Refresher Programme in Teaching (ARPIT). These online lecture courses are available on the SWAYAM platform for the University/College teachers. Large numbers of such teachers have taken advantage of these courses.

IUCAA has continued to be in the forefront of science popularisation and outreach activities for high school students and the general public. Regular Lecture/Demonstration Programmes for local school students have been conducted, and are very popular. During this year, bounded by pandemic restrictions, we have been able to translate all these activities to online ones, and in the process have been reaching much larger numbers all over the country.. The National Science Day programmes consisted of various competitions for school students, demonstrations, lectures, posters and model presentations, night sky watching, etc., were conducted online for two days during February 28 and 29, 2021. Outreach activities included





lectures/demonstrations/workshops conducted at different parts of Maharashtra and elsewhere - this included our rural outreach programmes around the LIGO-India site in the Hingoli district, and in the vicinity of IUCAA's own Girawali observatory. All these activities owe a great deal to the hard work by our talented staff (core and contractual) at IUCAA. I wish to express my sincere thanks to every one of them.

I would also like to express my deepest gratitude to our mentors, our Governing Board with Dr. K. Kasturirangan as Chair, and our Council, chaired by Dr. Dharendra P. Singh, Chairman of the UGC. We sincerely acknowledge the help, advice and support from the University Grants Commission and its officers and staff, and from the Ministry of Education (previously Human Resource Development) of the Government of India.

Somak Raychaudhury

Director, IUCAA

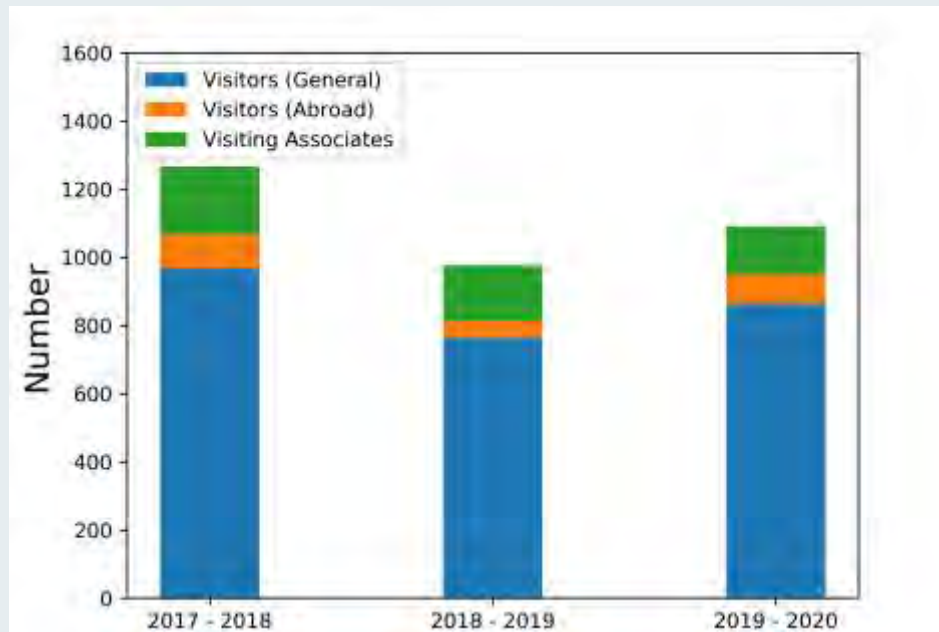


IUCAA IN NUMBERS



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Visitors to IUCAA



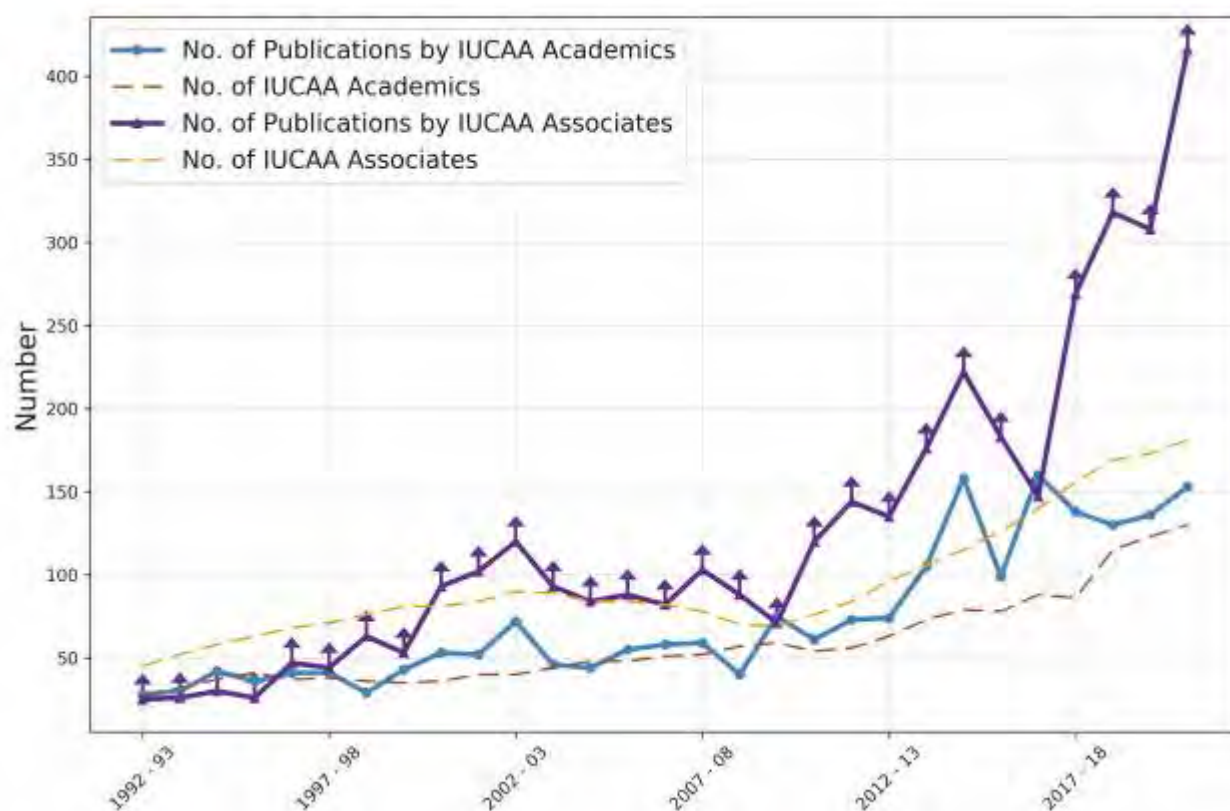
Since its inception, the IUCAA extended family of Visiting Associates has seen a steady growth over time, with an academic strength today nearly thrice its original number.

IUCAA Family across the Years





Publications across the Years

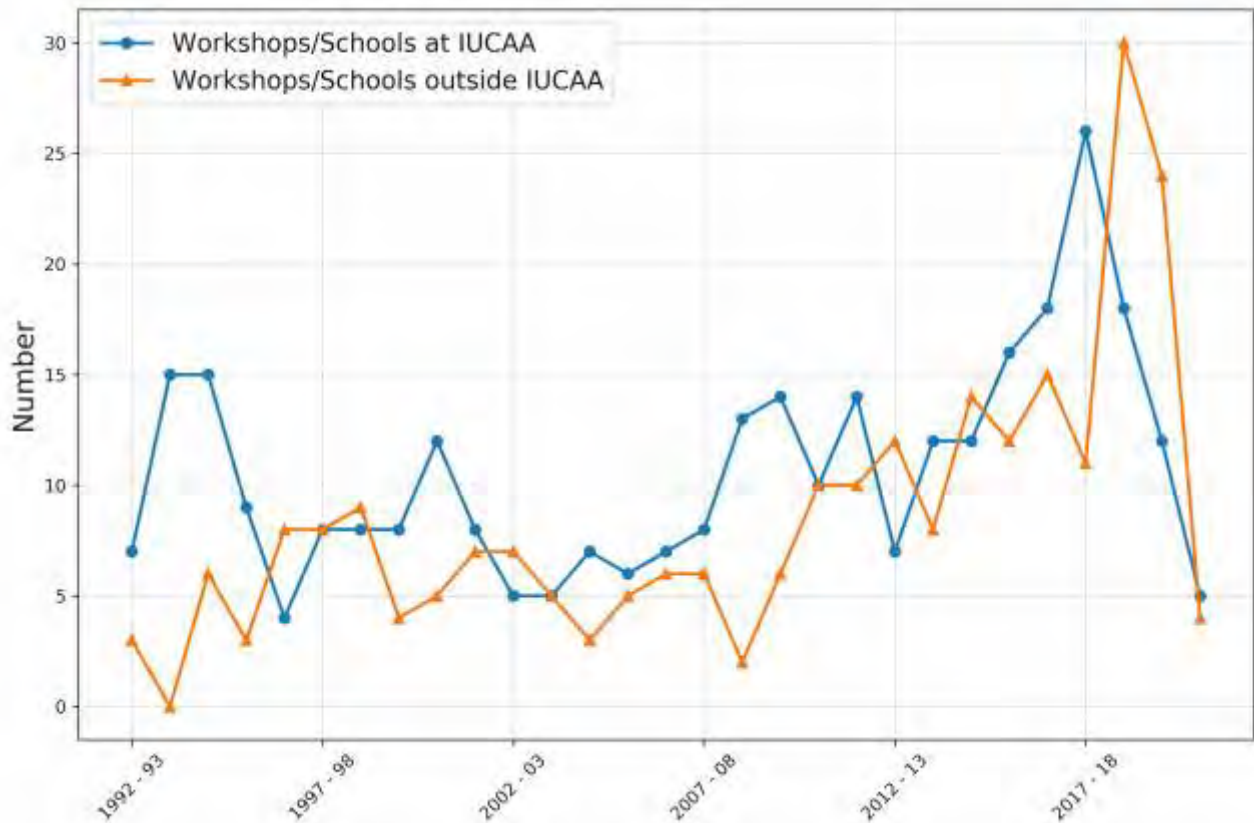


** Number of Publications by IUCAA Visiting Associates are underestimated.*

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



Workshops / Schools at IUCAA and outside IUCAA

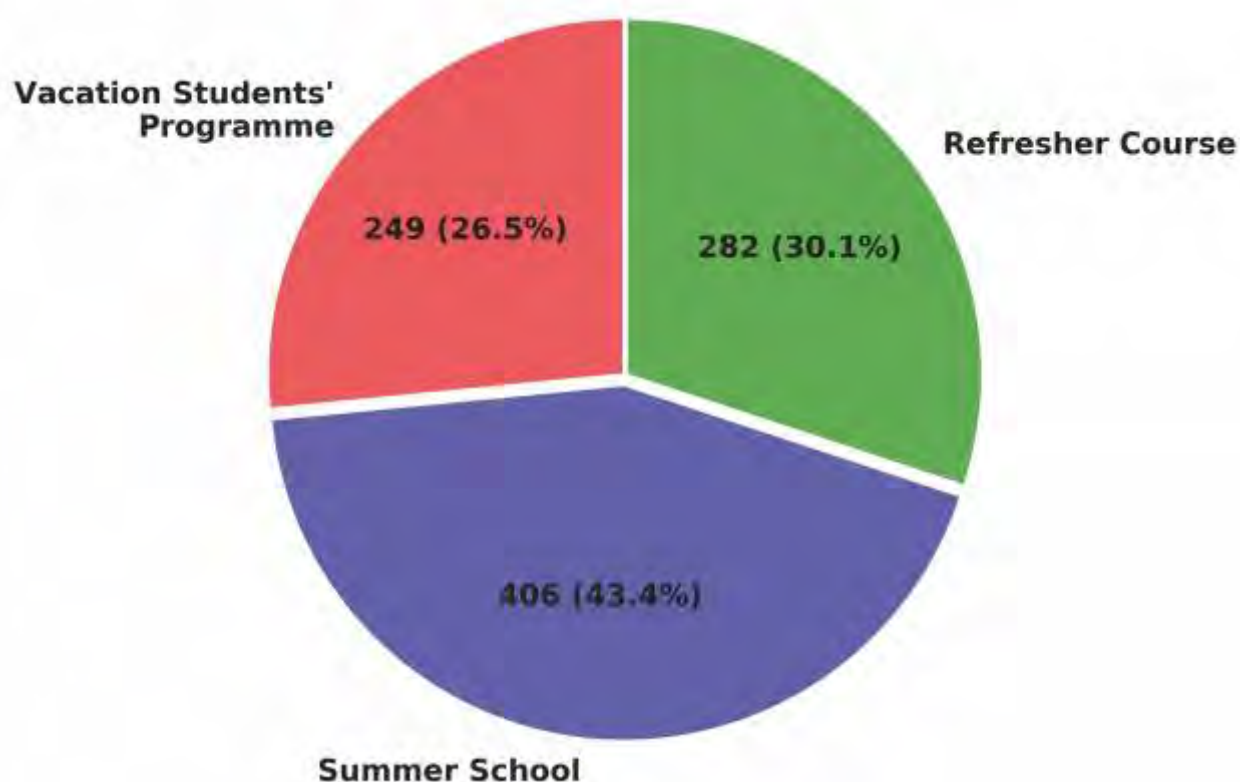


IUCAA is committed to fostering Astronomy and Astrophysics in the Universities, primarily through an increasing frequency of Workshops and Schools, both at and outside IUCAA.



Summer Programmes at IUCAA

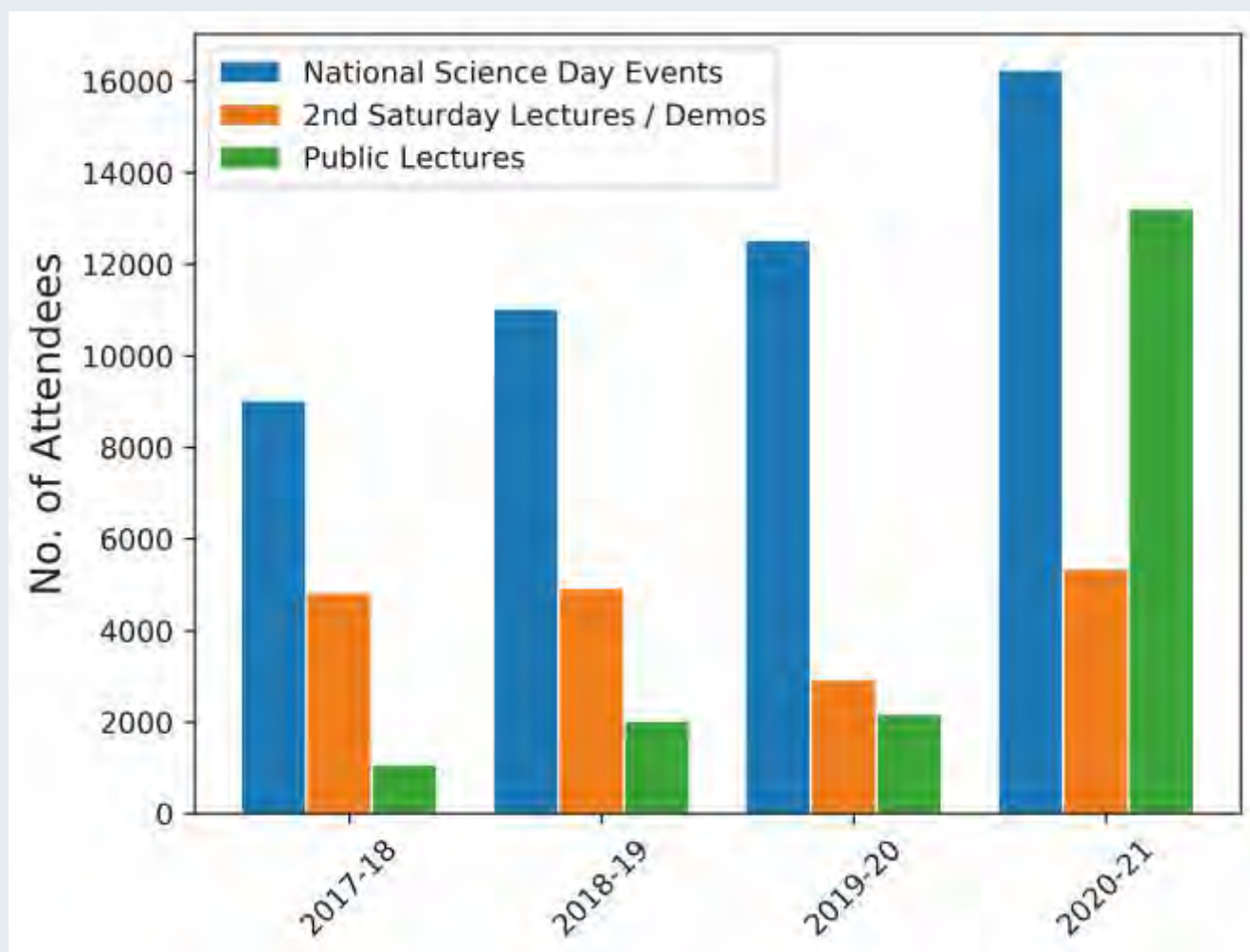
IUCAA also reaches about 200 students per year through the School Students' Summer Programme and Astronomy Camp, in addition to many other Outreach Activities and Events throughout the year.



IUCAA's Summer Programmes provide short, intense crash-courses in Astronomy and Astrophysics to budding researchers at the under-graduate and post-graduate levels through the Summer School and Vacation Students' Programme, as well as to seasoned teachers through the Refresher Courses.



Public Outreach Events at IUCAA



IUCAA also touches the lives of thousands of lay citizens each year through a variety of Public Outreach activities.



RESEARCH HIGHLIGHTS 2020-2021



MeerKAT array (South Africa)



The MeerKAT Absorption Line Survey (MALS) gets real!

Deep galaxy surveys have revealed that the global star formation rate (SFR) density in the universe peaks at $1 \leq z \leq 2$ and sharply declines towards $z = 0$. But a clear picture of the underlying processes, in particular, the evolution of cold atomic (~ 100 K) and molecular gas phases, that drive such a strong evolution is yet to emerge. In 2010, the MeerKAT Absorption Line Survey (MALS), led by IUCAA researchers **Neeraj Gupta** and **Raghunathan Srianand**, was identified as one of the ten large surveys to be carried out with MeerKAT radio telescope to better constrain the evolution of cold atomic and molecular gas in galaxies.

After a rigorous and successful telescope commissioning and science verification phase involving engineers and astronomers from the South African Radio Astronomy Observatory (SARAO), and the MALS team members, the MALS observations, finally started in June 2020. The 1,655 hrs of MALS with the MeerKAT radio telescope, which is currently the most sensitive telescope at cm wavelengths, will produce 1.5 PB of raw data! These data cannot be processed using traditional data processing approaches. IUCAA has set up a dedicated data processing facility to overcome this big data challenge.

MALS is currently producing the most sensitive spectra of radio sources ever taken by astronomers. Details of new exciting results from these early science data are described in the section “Research at IUCAA” later in this report.

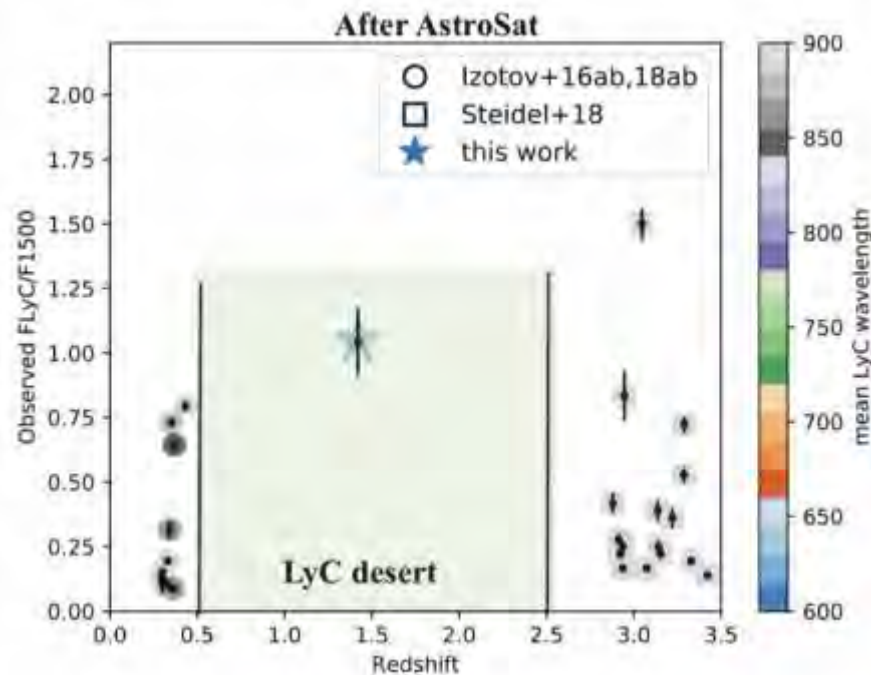
The large sample of HI and OH absorbers obtained from the survey will (i) lead to tightest constraints on the fundamental constants of physics, and (ii) be ideally suited to probe the evolution of magnetic fields in disks of galaxies via Zeeman Splitting or Rotation Measure synthesis. Through the excellent sensitivity of MeerKAT over a wide range of spatial resolutions and wideband spectro-polarimetry, MALS will simultaneously deliver a highly competitive blind HI/OH emission line and radio continuum survey, and will address a wide range of science issues relevant to Square Kilometer Array (SKA).



Lyman Continuum Emitting Galaxies from AstroSat UV Deep Field

One of the significant problems of current observational cosmology is understanding the nature of sources responsible for the reionization of our Universe. These are most likely the first galaxies, perhaps made from the PopIII stars, that formed after the Cosmic Dark Age. Direct detection of these reionization sources is practically infeasible at high redshift (z) due to the steep rise of the opacity of the intergalactic medium (IGM).

Over the last five years, there has been tremendous progress in this field, especially in terms of the detection of the low redshift analogs. For example, several green peas, the compact starburst galaxies at $z < 0.5$, are observed to be emitting Lyman continuum (LyC) photons at 900Å rest-frame. These detections have been possible because of the observations carried out by the HST Cosmic Origins Spectrograph. There are also detections of compact LyC galaxies in the range $2.5 < z < 3.5$. The redshift range $0.5 < z < 2.5$ has remained barren and has been termed as the LyC desert until the recent discovery of a LyC emitting galaxies at $z=1.42$ (Saha, et al. NatAst, 2020) based on the AstroSat UV Deep Field (AUDF) data.



The AUDF has been made based on the observations carried out by the Ultraviolet Imaging Telescope (UVIT) on AstroSat, India's first Space Observatory. It took about two years of constant effort involving running and benchmarking various versions of the pipeline, orbit by orbit analysis of the

Figure: AUDFs01 is the new newly discovered galaxy in the LyC desert

UVIT data, accurate astrometry, etc., to produce the first version of the science-ready images of the AUDF in two filters. AUDF is currently the deepest UV deep field, allowing one to study the farthest and faintest sources in the UV passband. In other words, AUDF enables one to study Extreme-UV (EUV) radiation from distant galaxies in the rest frame. The discovery of AUDFs01 is the first such example of the detection of EUV photons at rest-frame. Exciting science results are in the pipeline. We are currently in the process of analyzing multi-epoch far-UV observations on the same field. This work is led by **Kanak Saha** from IUCAA.



Hindustan Times

Iucaa-led team sees light... from 9.3bn light years away

Dheeraj Bhatnagar

PUNE: A team of international astronomers led by the scientists from the Inter-University Centre for Astronomy and Astrophysics (IUCAA) in Pune has laid claim to the discovery of UV light emanating from a galaxy called AUDFs01, which, according to Iucaa, is 9.3 billion light-years away from Earth.

The light was seen using "AstroSat", India's first multi-wavelength satellite. The multi-wavelength satellite has five unique X-ray and ultraviolet telescopes working in tandem. AstroSat was launched on September 28, 2015, by the Indian Space Research Organisation (ISRO) and has onboard the UltraViolet Imaging Telescope (UVIT).

The discovery was made by a team, led by Dr Kanak Saha, associate professor at Iucaa and the paper has been published on Monday by Nature Astronomy.

The team comprises scientists from Switzerland, France, USA, Japan and the Netherlands, apart from India. Saha and his team observed the galaxy which is located in the "Hubble Extreme Deep field", through AstroSat. These observations lasted for 21 hours in October 2016, but it took two years since then to carefully analyse the data to ascertain that the emission is indeed from the said galaxy. Since UV radiation is absorbed by Earth's atmosphere, it is detected from space.

"The light was seen using "AstroSat" (right), India wavelength satellite. Nasa's Hubble Space Telescope significantly larger than AstroSat, has not detected emission from this galaxy because it is too faint.

This discovery of AUDFs01 by AstroSat establishes that there is hope and perhaps, this is the beginning.

DR KANAK SAHA, associate professor at Iucaa

the background noise in the UVIT detector is much less than the

IUCAA and CSA of Govt of Sikkim professor would be vice the nity the extreme galaxy v not. Th by Ast there i the be "T don a ute to core the was AU pu

PuneMirror

5th Sept, 2021 | BANGALORE EDITION | BANGALORE MIRROR

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HOME | PUNE | PUNE | IUCAA TO BUILD QUANTUM LABORATORY ON PREMISES

IUCAA to build quantum laboratory on premises

PuneMirror | 5th September 2020 6:02 PM

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Its optical atomic clock will give most-accurate calculations

Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, has joined hands with Union government's initiative on quantum technologies. Taking it ahead, it will establish precision and quantum measurement laboratory (PQM-lab) on the campus. This facility will develop an optical atomic clock for the most-accurate calculations.

Professor Subhadeep De, who is leading the project, said, "This is a unique new addition to IUCAA's existing instrumentation facilities, which concentrate on advanced astronomical instrumentation — such as adaptive optics, imagers and spectrographs for ground based and space observatories."

Apart from contributing to nation's quantum research, this laboratory will help IUCAA in studying fundamental sciences. Furthermore, the technological outcomes from the PQM-lab will lead to products that can be commercialised. This will help foster technology-driven economic growth in India by import substitution and self-reliance. Other national mega-science initiatives are expected to reap benefits from the developed technologies at the PQM-lab.

ANNULAR SOLAR ECLIPSE ON JUNE 21

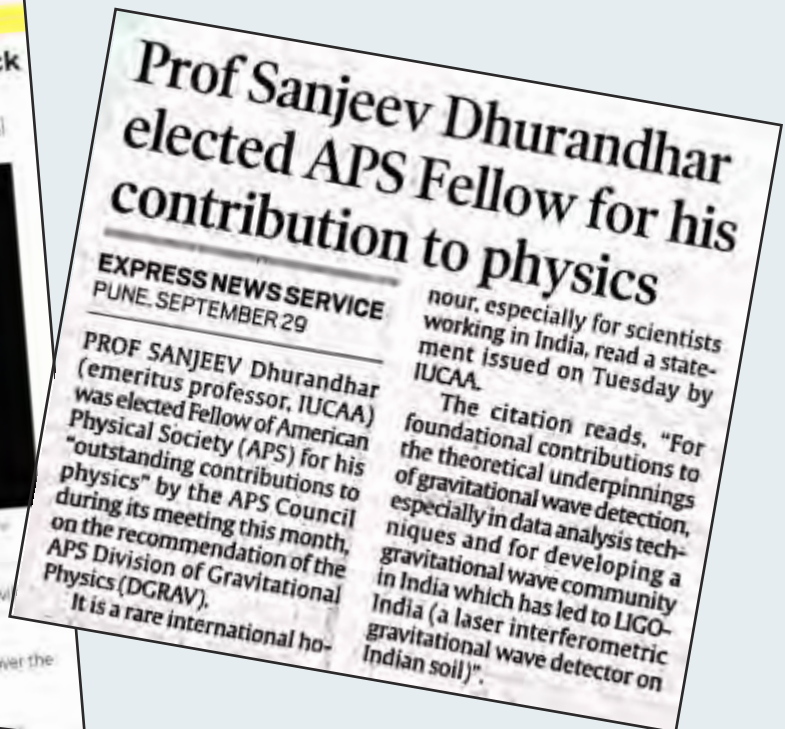
IUCAA to hold online sessions on solar eclipse

Pune: As the annular solar eclipse, which will be seen in parts of north India on June 21, draws near, the Inter-University Centre for Astronomy and Astrophysics in Pune will hold a series of interactive sessions on its YouTube channel (IUCAA SciPOP) on solar eclipses.

In Pune, the eclipse will begin at 10.02 am and is expected to reach its maximum phase at 11.40 am. It will end at 1.30 pm here. Across India, however, different phases of it should be visible between 10 am and 2 pm, depending on the longitude.

The hour-long IUCAA SciPOP

sessions will be held on June 18 and 19, in English and Marathi respectively. On June 21, the live online session will combine feeds from all over the country and host an array of experts from IUCAA and the scientific community on eclipses, astronomy and related fields. **ENS**







Global team of scientists discovers one of the earliest galaxies using India's AstroSat

AstroSat discovers one of the earliest galaxies in extreme ultraviolet light

By: Express News Service | Pune
Updated: August 25, 2020 11:02:28 am



In a major breakthrough, a global team led by scientists of the Inter University Centre for Astronomy and Astrophysics (IUCAA) has discovered one of the earliest galaxies in extreme ultraviolet light. AstroSat, India's first multi-wavelength satellite that has five unique X-ray and ultraviolet telescopes working in tandem, has detected extreme UV light from a galaxy called AUDFs01, 9.3 billion light-years away from Earth.

The discovery was made by a team, led by Dr Kanak Saha, associate professor at IUCAA and the paper has been published on Monday by Nature Astronomy.

Hindustan Times

Monday, Jan 17, 2022 New Delhi 11°C

Home / Science / Astronomers led by Iucaa team detect UV light from galaxy 9.3 billion light-years away from Earth

The discovery was made by a team, led by Dr Kanak Saha, associate professor at Iucaa and the paper has been published on Monday by Nature Astronomy.



Light from young galaxy born in baby universe spotted

Kalyan Ray, DHNS, AUG 26 2020, 23:14 (IST) | UPDATED: AUG 25 2020, 19:44 (IST)



Representative image: iStock Photo

Using India's very own space observatory Astrosat, a bunch of Indian researchers in collaboration with their partners from the USA, Europe and Japan on Monday reported spotting the signatures of one of the first galaxies that were born when the universe was only one-third of its age.

The discovery opens up a new window to look at the universe at a time when light came into being after the Cosmic Dark Age.

at multi-wavelength satellite. (Unsplash)

's first multi-wavelength satellite has five unique X-ray and ultraviolet telescopes working in tandem, as launched on September 28, 2015 (ISRO) and has onboard

Dr Kanak Saha, associate professor at IUCAA and the paper has been published on Monday by Nature Astronomy.

nd, France, USA, Japan and

s located in the "Hubble observations lasted for 28 hours then to carefully analyse the data from the said galaxy.



PuneMirror PUNE ENTERTAINMENT NEWS IUCAA to build quantum premises

By PuneMirror Desk / Tue, 11 Aug 2020

Its optical atomic clock will give most-accurate calculations

Inter-University Centre for Astronomy and Astrophysics (IUCAA) on quantum technologies. Taking it ahead, it will establish precise campus. This facility will develop an optical atomic clock for the

Professor Subhadeep De, who is leading the project, said, "The facilities, which concentrate on advanced astronomical instruments for ground-based and space observatories."

Apart from contributing to nation's quantum research, this lab. Furthermore, the technological outcomes from the PQM-lab foster technology-driven economic growth in India by impeding initiatives are expected to reap benefits from the developed technologies.

Somnath Raychaudhary, director of IUCAA, said, "We are proud that IUCAA has been able to transform into practical also. The laboratory will make atomic clock, which is accurate, and will also be helped in various national projects."

He informed that IUCAA has been actively participating with IISER Pune in its recently approved Technology Innovation Hub under the National Mission on Interdisciplinary Cyber Physical Systems programme, which will develop quantum technologies. IUCAA and IISER-Pune will together deploy an ultra-stable optical fibre link (quantum channel) between two atomic clocks at the two institutions.

EXPRESS NEWS SERVICE
PUNE, AUGUST 24

The team, which comprises scientists from India, Switzerland, France, the US, Japan and The Netherlands, used AstroSat, which has five X-ray and ultraviolet

Dr Kanak Saha, associate professor of astronomy at IUCAA who led the team, told *The Indian Express* that the team observed the galaxy which is located in the Hubble Extreme Deep field, through AstroSat. The findings were published on August 24 by *Nature Astronomy*.

A statement is explained.

According to the statement, a few hundred million years after the Big Bang, the universe ended when the first galaxies formed and began pouring out from the hydrogen and

Raychaudhury said this was a very important discovery to understand how the "dark ages" of the universe ended and there was light in the universe. "We need to know when this started, but it has been very hard to find the earliest sources of light," Raychaudhury said.

"We knew it would be an uphill task to convince the in-

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Pune Mirror

IUCAA to build quantum laboratory on premises

Its optical atomic clock will give most-accurate calculations

Its optical atomic clock will give most-accurate calculations.

Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, has joined hands with Union government's initiative on quantum technologies. Taking it ahead, it will establish precision and quantum measurement laboratory (PQM-lab) on the campus. This facility will develop an optical atomic clock for the most-accurate calculations.

Professor Subhadeep De, who is leading the project, said, "This is a unique new addition to IUCAA's existing instrumentation facilities, which concentrate on advanced astronomical instrumentation — such as adaptive optics, imagers and spectrographs. For ground based and space observatories."

For quantum research, this laboratory will help in developing quantum technologies.

Apart from contributing to nation's quantum research, this laboratory will help studying fundamental sciences. Furthermore, the technological outcomes of PQM-lab will lead to products that can be commercialised. This will help in technology-driven economic growth in India by import substitution and so on. Other national mega-science initiatives are expected to reap benefits from the developed technologies at the PQM lab.

Somnath Raychaudhuri, director of IUCAA, said, "We are proud that it is to transform from theoretical projects into practical also. The laboratory will be an atomic clock, which is accurate and will also be helped in various other experiments. We are participating with IISc."

He informed that IUCAA has been actively participating with ISRO in the development of atomic clocks, which is accurate, and... **It is a rare in**

approved Technology Innovation Hub under the National Mission on Interdisciplinary Cyber Physical Systems programme, which will develop quantum technologies. IUCAA and ISER-Pune will together deploy an ultra-stable optical fibre link (quantum channel) between two atomic clocks at the two institutions.

**Prof Sanjeev Dhurandhar
elected APS Fellow for his
contribution to physics**

EXPRESS NEWS SERVICE
PUNE, SEPTEMBER 29

nour, especially for scientists working in India, read a statement issued on Tuesday by IUCAA.

PROF SANJEEV Dhurandhar (emeritus professor, IUCAA) was elected Fellow of American Physical Society (APS) for his "outstanding contributions to physics" by the APS Council during its meeting this month, on the recommendation of the APS Division of Gravitational Physics (DGRAV).

It is a rare international ho-

The citation reads, "For foundational contributions to the theoretical underpinnings of gravitational wave detection, especially in data analysis techniques and for developing a gravitational wave community in India which has led to LIGO-India (a laser interferometric gravitational wave detector on Indian soil)".



IUCAA ACADEMIC CALENDAR

(All the events were conducted online)



33rd
ANNUAL REPORT
2020-21

ANNUAL EVENTS AT IUCAA

2020

May 11 – June 12

Introductory Summer School on Astronomy and Astrophysics

(for College and University Students),
and

Refresher Course on Astronomy and Astrophysics

(for College and University Teachers)

December 28 – January 9

IUCAA - NCRA Radio Astronomy Winter School

Coordinators: D. J. Saikia | Jameer Manur | Subhashis Roy | Ruta Kale

December 29

Foundation Day

2021

February 28

National Science Day





EVENTS AT IUCAA

2020

July – September

An Introduction to Optical and Infrared Interferometry

Coordinator: Prakash Arumugasamy

2021

January 5 – April 1

Advanced Course on Pulsar Astrophysics

Coordinator: Prakash Arumugasamy

January 27 – April 9

Introductory Course on Astronomy and Astrophysics

Coordinators: Gazi Ahmed | Rupjyoti Gogoi | Dhruva J. Saikia.

EVENTS OUTSIDE IUCAA

2020

November 10 – 13

North – East Meet of Astronomers (NEMA – VI)

Coordinated at: IIT, Guwahati

December 5 – 7

Workshop on Ultraviolet Astronomy

Coordinated at: Mahatma Gandhi University, Kottayam

Coordinators: K. Indulekha | K. Saha

2021

February – March

Course in General Relativity

Coordinated at: Institute of Advanced Research, Gandhinagar

Coordinators: G. Gauri | R. Misra

February 18 – 21

Workshop on Ultraviolet Space Astronomy: UVIT and Beyond

Coordinated at: 39th Meeting of the ASI

Co-organizers: Maheswar Gopinathan ++ Kanak Saha



AWARDS AND DISTINCTIONS

Sanjeev V. Dhurandhar

Fellow, American Physical Society, for foundational contributions to the theoretical underpinnings of gravitational wave detection, especially in data analysis techniques, and for the development of India's gravitational wave community leading to LIGO – India, September 2020.

Samir Dhurde

Astronomical Society of India's **Zubin Kembhavi Award**, for public outreach and education in astronomy and allied fields, shared with Vivek Monteiro.



Neeraj Gupta, and team

AAAS Newcomb Cleveland Prize (2021), for Keith W. Bannister, Adam T. Deller, Chris Phillips, Jean-Pierre Macquart, ..., Neeraj Gupta, et al. (2019) *A single fast radio burst localized to a massive galaxy at cosmological distance*, Sci, **365**, 565, [<https://www.aaas.org/awards/newcomb-cleveland-prize/about>].

Jayant V. Narlikar

- **President, 94th Akhil Bharatiya Marathi Sahitya Sammelan** (94th All India Marathi Literary Meet).
- **Krishnaji Medal** (Lecture Award), National Academy of Sciences, India

T. Padmanabhan

Fifth Prize in the Gravity Research Foundation Essay Contest (2020) for Principle of equivalence at Planck scales and the zero-point length of spacetime: A synergistic description of quantum matter and geometry, IJMPD, 29, 2042005.

Kanak Saha, Shyam N. Tandon, and team

New Discovery Award, for their work on detection of Lyman continuum emission from a $z = 1.42$ galaxy using AstroSat.



RESEARCH GRANTS AND FELLOWSHIPS

Dipankar Bhattacharya

- ISRO Grant to set up the AstroSat Science Support Cell (ASSC).

Subhadeep De

- DST grant for the project: Quantum Information Technologies with ion-trap and optical-lattice devices of Interdisciplinary Cyber Physical Systems.

Sanjeev Dhurandhar

- NASI Senior Scientist Platinum Jubilee Fellowship.

Shabnam Iyyani

- DST – INSPIRE Faculty Fellowship

Ajit Kembhavi

- Grant for the Pune Knowledge Cluster.

Sanjit Mitra

- DST SwarnaJayanti Fellowship for the project: Gravitational Waves Astronomy with a Network of Ground-based Detectors.

T. Padmanabhan

DST J.C. Bose (Second) Fellowship.

IshaPahwa

- DST – INSPIRE Faculty Fellowship.

A.N. Ramaprakash

- Participation Grant in Thirty Metre Telescope Project.
- ISRO Grant for the Design, Development, Assemble, Test, Calibrate the Solar Ultraviolet Imaging Telescope (SUIT) payload for Aditya – L1 Mission.



- Infosys Foundation Grant for Resurgent Caltech – IUCAA Collaboration for Advanced Instrument Development and Scientific Discoveries.
- ISRO – ISAC Grant.

Kanak Saha

- CEFIPRA Grant for the project: The Assembly History of Disk Galaxies over the Last 8 Billion Years.
- Grant for the project: Exploring the Nature of Lyman Continuum Emitting Sources in the AstroSat – UV Deep Field.

Varun Sahni

- DST J.C. Bose Fellowship.

Durgesh Tripathi

- Indo – German (DST – Max Planck Society) Partner Group Research Grant for Coupling and Dynamics of Solar Atmospheric project.

OTHER GRANTS TO IUCAA

- Teaching Learning Centre (TLC) Grant for the project under the Pandit Madan Mohan Malaviya National Mission on Teachers and Teaching (PMMMNMTT).
- National Resource Centre (NRC) for Astronomy and Astrophysics for the project under the PMMMNMTT.
- Annual Refresher Programme in Teaching (ARPIT) for Astronomy and Astrophysics Grant under the PMMMNMTT.
- DST – DAE Grant for Technology Development and Capacity Building for Gravitational Waves Detection (LIGO – TDCB).
- DST – DAE Grant for LIGO – India SEED.



Cosmology and Structure Formation

Curing inflationary degeneracies using reheating predictions and relic gravitational waves

There has been a remarkable progress in our understanding of the early universe over the past three decades, fostered by new theoretical insights and reinforced by a plethora of precision cosmological missions, ranging from Cosmic Microwave Background (CMB) to large scale structure (LSS) observations. As a result, the inflationary paradigm has emerged as a key scenario for describing the early universe and for setting initial conditions for the hot big bang phase of expansion. One of the key predictions of the inflationary scenario is the quantum-mechanical production of primordial tensor fluctuations which give rise to a stochastic background of relic gravitational waves. The reason for this lies in the fact that unlike other massless fields, such as photons and massless neutrinos which couple conformally to gravity and whose production is, therefore, suppressed in the conformally flat Friedmann-Lemaître-Robertson-Walker (FLRW) universe, gravitational waves couple minimally to gravity, which results in their non-adiabatic production in an expanding universe. While several distinct predictions of the single field slow-roll scenario of inflation have received spectacular observational confirmation, both from CMB as well as LSS observations, the detection of primordial tensor fluctuations, both in the form of CMB B-mode polarization on large angular scales as well as a spectrum of relic gravitational waves (GWs), remains one of the major challenges confronting observational cosmology in the coming decade.

It is well known that GWs provide us with important information about the nature of the inflaton field and its potential. Of equal importance is the fact that their spectrum, $\Omega_{\text{GW}}(k)$, and spectral index $n_{\text{GW}} = \frac{d \log \Omega_g}{d \log k}$, can serve as a key probe to physical processes occurring after inflation. The spectrum of relic gravitational radiation is exceedingly sensitive to the post-inflationary equation of state (EoS), w . In fact the GW spectrum has distinctly different properties for stiff/soft EoS. For a stiff EoS, $w > 1/3$, the GW spectrum shows a blue tilt: $n_g > 0$, which increases the GW amplitude on small scales. Softer EoS, $w < 1/3$, on the other hand, lead to a red tilt, whereas the radiative EoS, $w = 1/3$, results in a flat spectrum with $n_g \simeq 0$.

Another key aspect of inflationary cosmology, namely the epoch of ‘reheating’, also remains observationally inaccessible at present, despite a profusion of theoretical progress in this direction. It is well known that the post-inflationary universe passed through a series of physical epochs, each of which can be characterized by an EoS, w_i . Of these, the most recent ones are: the radiative stage with $w_r \simeq 1/3$, the matter dominated stage with $w_m \simeq 0$, and the present stage of accelerated expansion with $w_{\text{de}} < -1/3$. However, after the end of inflation and before the commencement of

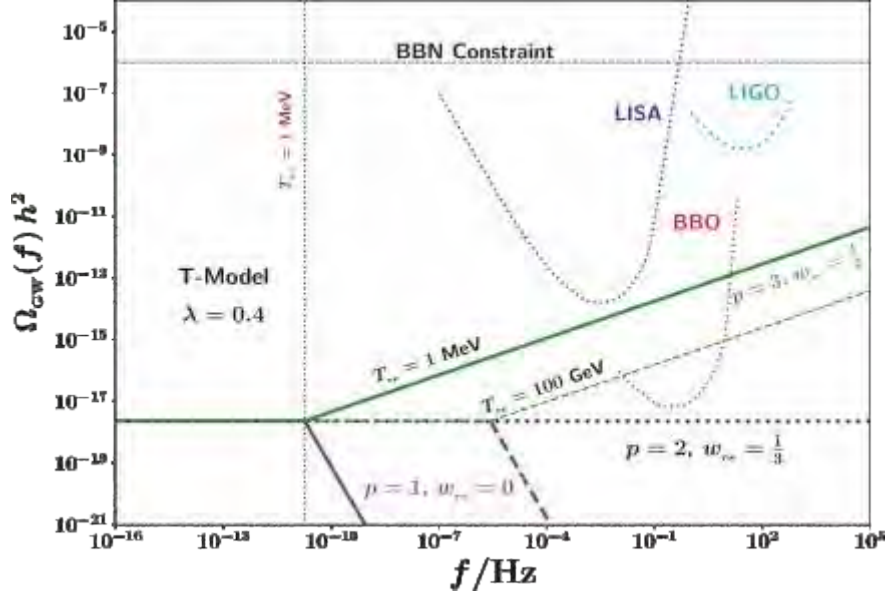


Figure 1: The spectrum of relic gravitational waves is shown for the T-model α -attractor potential $V(\phi) = V_0 \tanh^{2p}(\lambda\phi/m_p)$; $p = 1, 2, 3, \dots$, for $\lambda = 0.4$. The dotted black curve corresponds to $p = 2$ for which the post-inflationary EoS is radiation-like, with $w_{\text{re}} = \langle w_\phi \rangle = 1/3$, where $\langle w_\phi \rangle = \frac{p-1}{p+1}$, and the GW spectrum is flat. The solid and dashed green curves correspond to $p = 3$ and reheating temperatures $T_{\text{re}} = 1 \text{ MeV}$ and 100 GeV respectively, for which the post-inflationary EoS is $w_{\text{re}} = \langle w_\phi \rangle = 1/2$ and the resulting GW spectrum has a blue tilt. One finds that in this case relic gravity waves can be detected by future GW observatories such as BBO, for a range of reheating temperature $T_{\text{re}} \leq 10^6 \text{ GeV}$. The solid and dashed purple curves correspond to reheating temperatures $T_{\text{re}} = 1 \text{ MeV}$ and 100 GeV respectively, and to a matter-like post inflationary EoS $w_{\text{re}} = \langle w_\phi \rangle = 0$, which arises for $p = 1$. Note that in this case, GWs have a red tilt and their amplitude is suppressed relative to $p = 2, 3$.

the radiative stage, the universe went through a pre-radiative epoch of reheating, during which the energy contained in the inflaton field was transferred to the other matter/radiative degrees of freedom present in the universe. The nature of the pre-radiative epoch, including its duration, N_{re} and EoS, w_{re} depends crucially upon how the inflaton couples with (and hence, releases its energy into) the other matter fields in the universe. If this process is slow then reheating takes place perturbatively and the scalar field oscillates for a very long time, gradually releasing its energy into matter/radiation. In this case, the EoS during the oscillatory regime is determined primarily by the shape of the inflaton potential near its minimum value, about which the inflaton oscillates. Perturbative reheating is expected to occur if the inflaton decays primarily into Fermions (which soon decay into the standard model fields), its decay into Bosons being strongly suppressed.

On the other hand, if the inflaton decays into Bosons, χ , through a coupling



$g^2\phi^2\chi^2$ with $g \gg 10^{-3}$, then oscillations of ϕ can lead to a parametric resonance, during which quanta of the field χ are produced in copious amounts. This stage is usually referred to as pre-heating. The backreaction of χ on ϕ ends the resonance and the subsequent decay of excitations of the ϕ and χ fields into standard model (SM) fields gives rise to reheating and the subsequent thermalization of the universe at a temperature T_{re} . The duration of the pre-radiative epoch, which includes the end of inflation, the parametric resonance, the decay of the inflaton into Bosons ($\phi \rightarrow \chi\chi$) and Fermions ($\phi \rightarrow \psi\psi$) and thermalization can be quite long, and it is convenient to encode its physics by means of an effective EoS parameter w_{re} . Since w_{re} influences the spectrum of relic gravitational waves, observations of the GW spectrum can shed light on the complex, non-linear and out of equilibrium physics which operates during the reheating epoch.

In addition to primordial tensor fluctuations which result in the GW background, a key prediction of inflationary cosmology is the generation of primordial scalar fluctuations which later grow to form the LSS of the universe. Scalar and tensor perturbations generated during inflation create an imprint in the CMB, which can be used to deduce the scalar spectral index n_s , and the tensor to scalar ratio r – two important observables which can be used to rule out competing inflationary models. However, it is well known that inflationary models often display degeneracies, with two (or more) models predicting essentially the same values of $\{n_s, r\}$. This leads to so called ‘cosmological attractors’ or ‘universality classes’ of the inflationary scenario. This degeneracy makes it difficult for CMB observations alone to constitute a unique probe of inflationary cosmology.

Swagat Mishra, Varun Sahni, and Russian physicist Alexei Starobinsky have shown that reheating predictions including the reheating duration N_{re} , temperature T_{re} and particularly the EoS w_{re} , can help break degeneracies in inflationary scenarios, in which identical values of $\{n_s, r\}$ can correspond to different w_{re} . Since the gravitational wave spectrum $\Omega_{\text{GW}}(k)$ is sensitive to the value of w_{re} , observations of $\Omega_{\text{GW}}(k)$ by space-based GW observatories can shed valuable light both on the dynamics of reheating as well as on the parameters of the inflationary potential as shown in Figure 1.

Multi-wavelength mock galaxy catalogues of the low-redshift universe

Aseem Paranjape, Tirthankar R. Choudhury, and Ravi K. Sheth have presented an updated empirical algorithm for generating mock galaxy catalogues using $z = 0$ outputs of gravity-only N-body simulations, painting in galaxies whose properties match observed abundances and clustering at $z \lesssim 0.1$ of optically selected SDSS and HI-selected ALFALFA galaxies. The mock central and satellite galaxies are assigned realistic values of r-band luminosities, optical colours, stellar mass, and for a fraction of galaxies, neutral hydrogen (HI) mass. Additionally, the host halos of central galaxies are baryonified with realistic spatial distributions of stars, cold gas, hot ionised gas, and gas affected by feedback, with a dark matter profile that responds to the presence of these baryons according to a quasi-adiabatic relaxation process fit to hydrodynamical simulations. This novel combination of modelling ingredients



allows each mock central to be assigned a realistic rotation curve. These mocks facilitate novel tests of the galaxy-dark matter connection in the Λ CDM framework, which they have explored in other work.

The radial acceleration relation in a Λ CDM universe

The mock catalogues described above allow to study the Λ CDM prediction for the radial acceleration relation (RAR) between the total and baryonic centripetal accelerations of rotationally supported galaxies, which has been performed by **Aseem Paranjape**, and Ravi K. Sheth. The baryonification scheme further leads to analytical insights, which clarify many observed trends in the shape and scatter of the RAR, along with their dependence on galaxy properties. A particularly striking result, which has been overlooked in the literature so far, is that the RAR is closely linked to the physics of quasi-adiabatic relaxation mentioned above. In particular, the shape and scatter of the RAR at baryonic accelerations $\gtrsim 10^{-10} \text{ m s}^{-2}$ is a strong function of the amount of angular momentum loss during the formation of the galactic disk. This motivates a deeper study of this relaxation mechanism in hydrodynamical simulations and its relation to galaxy and halo properties.

Distribution of HI velocity profiles in a Λ CDM universe

The HI-bearing central galaxies in the mock catalogues described above can be observed in the simulation by modelling the Doppler-shifted 21 cm line emission of HI of their differentially rotating disks. The resulting distribution of velocity profiles constitutes a prediction of Λ CDM and is potentially a novel probe of the baryon-dark matter connection. **Aseem Paranjape**, **Raghunathan Srianand**, Tirthankar R. Choudhury, and Ravi K. Sheth have explored this distribution as it would be inferred from surveys such as ALFALFA. The resulting comparison with the observed ALFALFA velocity width function shows good agreement for the sample produced using a minimal, default set of assumptions about the baryon-dark matter connection, and the mock catalogues allow an exploration of the sensitivity of the width function to changing these assumptions. The authors also propose the excess kurtosis of the velocity profiles, and its relation with the velocity width, as a novel probe of the physics of the turbulent HI disk.

Halo assembly bias: Calibrations and mocks

Halo assembly bias is a potential source of systematic uncertainty for cosmological inference from upcoming large-volume galaxy surveys, as well as being a possible channel for enhancing understanding of galaxy formation and evolution. The aim has been to develop accurate calibrations of the dependence of halo bias on one of the primary beyond halo mass variables responsible for assembly bias, namely, the tidal anisotropy of the local cosmic web environment of haloes. Here, **Sujatha Ramakrishnan**, and **Aseem Paranjape** used the Separate Universe (SU) technique to calibrate the dependence of linear and quadratic bias b_1 and b_2 , respectively, on

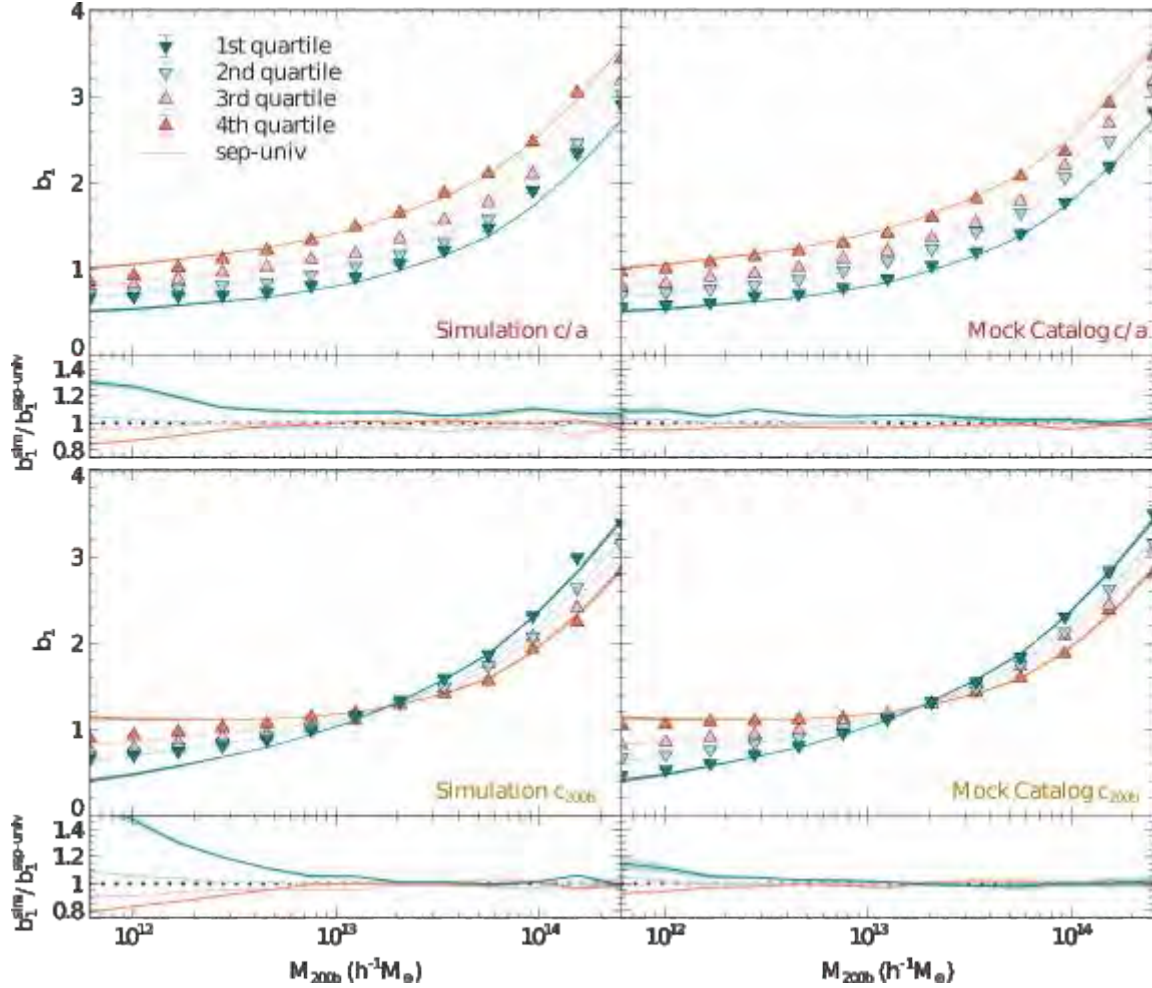


Figure 2: Halo assembly bias with respect to halo shape and concentration. The solid lines show the Separate Universe calibrations corresponding to four quartiles of a halo property. The data markers in the left panel show comparison with the simulation, while the right panel shows comparison with mocks. Low-mass haloes resolved with < 300 particles (halo masses $4.6 \times 10^{12} h^{-1} M_{\odot}$) in the simulation (left hand panels) fail to reproduce the full strength of assembly bias, while corresponding haloes in the mock catalogues (right hand panels) perform much better down to a 30 particle threshold.



halo mass, redshift and tidal anisotropy. An example use of this calibration to further calibrate the dependence of bias on other secondary properties is shown by solid lines in Figure 2.

In another work, **Sujatha Ramakrishnan**, **Aseem Paranjape**, and Ravi K. Sheth demonstrated that the large and small-scale halo clustering in a halo sub-population (selected by a particular halo property) remains invariant under a random shuffling operation of halos within bins of mass and halo environment. Fitting functions are provided for five halo properties as a function of halo mass and halo environment. These will be useful for large-volume/approximate method simulations, since most of them to accurately reproduce the mass function and cosmic web structure, but not the internal properties of the halo. They demonstrate that this is indeed the case for large-volume and low resolution N-body simulations and apply the fitting functions to increase the accessible dynamic range (see data markers in Figure 2).

Astrobiology

The astrobiology experiment by **Jayant V. Narlikar**, and collaborators is making progress on the front of instrumentation. The progress is slow because of problems with COVID-19. At present checks are being made under the auspices of Physical Research Laboratory, Ahmedabad on the instrument for measuring the Carbon isotope ratios at the microbial level.

Observational Cosmology and Extragalactic Astronomy

Inference of H_0 from binary black hole-galaxy cross-correlations

The discovery of gravitational waves (GW) has opened up a new window to probe the universe, and provides a direct measurement of the luminosity distance to the source. If the redshift of the source can be determined either through direct electromagnetic observations of the source or its host galaxy, then these observations can be used to constrain the Hubble constant. Although, there are many GW events observed so far, an electromagnetic counterpart has been observed, thus far only for a single merger event of binary neutron stars. A substantial number of events are a result of the merger of binary black holes which are not expected to emit any electromagnetic radiation.

Surhud More, and collaborators have shown how the angular clustering between GW standard sirens and galaxies with known redshifts allow an inference of the Hubble constant regardless of whether the host galaxies of any of these sirens are present in the galaxy catalogue. Such possible inference has been demonstrated for the first time with realistic simulations of GW signals from binary black holes in a three-detector network with Advanced LIGO and Advanced Virgo sensitivities. With such a network, the cross-correlation technique can be used to infer the Hubble



parameter with a precision of less than 10% (2%) at 90% confidence with 50 (500) sources, even with a 100% incomplete catalogue, which does not contain the hosts of any of the GW events. The method has been also compared with the current state-of-the-art techniques used for the inference of the Hubble parameter from real data and it has been argued that, if the clustering information is not used explicitly, the inference of H_0 from real data is expected to be dominated by implicit priors.

Observing correlations between dark matter accretion and galaxy growth

The correlation between fresh gas accretion on to halos and galaxy star formation is critical to understand galaxy formation. Different theoretical models have predicted different correlation strengths between halo accretion rates and galaxy star formation rates, ranging from strong positive correlations to little or no correlation. **Surhud More**, and collaborators have presented a technique to observationally measure this correlation strength for isolated Milky Way-mass galaxies with $z < 0.123$. This technique is based on correlations between dark matter accretion rates and the projected density profile of neighbouring galaxies; and these correlations also underlie past work with splashback radii. This new technique has been applied to both observed galaxies in the Sloan Digital Sky Survey as well as simulated galaxies in the UNIVERSEMACHINE, a simulated universe, where tests of any desired correlation strength could be carried out. The results showed that positive correlations between dark matter accretion and recent star formation activity have been ruled out with greater than 85 per cent confidence. These results suggest that star formation activity may not be correlated with fresh accretion for isolated Milky Way-mass galaxies at $z = 0$, and that other processes, such as gas recycling, dominate further galaxy growth.

Survey of gravitationally lensed objects in HSC imaging

Anton T. Jaelani, Cristian E. Rusu, Issha Kayo, **Anupreeta More**, Alassandro Sonnenfeld, et al. present spectroscopic confirmation of three new two-image gravitationally lensed quasars, compiled from existing strong lens and X-ray catalogues. Images of HSC~J091843.27-022007.5 show a red galaxy with two blue point sources at either side, separated by 2.26 arcsec. This system has a source and a lens redshifts $z_s = 0.804$ and $z_l = 0.459$, respectively, as obtained by our follow-up spectroscopic data. CXCO J100201.50+020330.0 shows two point sources separated by 0.85 arcsec on either side of an early-type galaxy. The follow-up spectroscopic data confirm the fainter quasar which has the same redshift with the brighter quasar from the SDSS fibre spectrum at $z_s = 2.016$. The deflecting foreground galaxy is a typical early-type galaxy at a redshift of $z_l = 0.439$. SDSS J135944.21+012809.8 has two point sources with quasar spectra at the same redshift $z_s = 1.096$, separated by 1.05 arcsec, and fits to the HSC images confirm the presence of a galaxy between these. These discoveries demonstrate the power of the Hyper Suprime-Cam Subaru Strategic Program (HSC-SSP)'s deep imaging and wide sky coverage. Combined with existing X-ray source catalogues and follow-up spectroscopy, the HSC-SSP pro-



vides us unique opportunities to find multiple-image quasars lensed by a foreground galaxy.

Extragalactic Astronomy

Three-and two-point spatial correlations of IGM at $z \sim 2$

Matter distribution in the intergalactic medium (IGM) is well probed by the Ly α forest absorption seen in the spectra of quasars. Clustering studies of Ly α absorption is an important tool in this regards. In particular, studying the higher order statistics is very important to probe the non-Gaussianity in the matter distribution (primordial and those introduced by the non-linear evolution of gravitational clustering) and to understand the evolution of matter beyond the linear approximation. The first significant order beyond the two point correlation function (or power spectrum in the Fourier space) is the three point correlation function (or bi-spectrum in the Fourier space). It has also been pointed out that one will be able to lift the degeneracy between different cosmological parameters (like bias and σ_8) by simultaneous usage of two- and three-point correlation functions. Till date, considerable work has been done on three-point correlation function of galaxies from large surveys.

Traditionally, the three-point correlation is quantified using the dimension less “Q” parameter called the “reduced three-point correlation”. The typical Q value is found to be ~ 1.3 with a moderate dependence on the shape of the matter power spectrum and shape of the triangle (i.e., configuration). The dependence of Q on the shape of the triangle is used to quantify the nature of the structure probed at different scales. While compact spherically symmetric structures (probed by equilateral configurations) dominate at small scales, the filamentary structures dominate at large scales (probed by linear configurations). It has been found that more luminous and massive galaxies (having high stellar mass) clustered strongly compared to less luminous and less massive (having low stellar mass). It has been also found that three point correlation function exhibits stronger dependence on both galaxy luminosity and stellar mass than Q. No significant redshift evolution is found for the angular dependence of Q at small scales. The redshift evolution noticed for the larger scales (i.e., > 15 Mpc) are consistent with the expectations of growth structures at low- z .

As far as the higher order correlation studies of IGM is concerned, very little work has been done with three-point statistics. Most of the earlier studies focus on obtaining 1D bi-spectrum of Ly α forest considering three points along a single sightline. This statistics with inherently weak signals due to Ly α being in mildly non-linear regime, will be largely affected by the spectral signal to noise and thermal broadening effects at small scales. So, working with closely spaced quasar triplets to probe the transverse clustering will provide us with a better insight into the non-Gaussianity involved with the matter distribution at such scales. Three-point correlation (or bi-spectrum) studies of transmitted flux can be extended to even higher redshifts, where the density fields are more linear and can be helpful in placing stronger constraints on the nature of the dark matter. It will also be helpful in studying the effect of fluctuating ionizing field during He II reionization.



Ly α forest absorption spectra decomposed into multiple Voigt profile components (clouds) allow us to study clustering of IGM as a function of H I column density (N_{HI}). Recently, **Soumak Maitra, Raghunathan Srianand, Aseem Paranjape**, and collaborators (Prakash Gaikwad, Tirthankar R. Choudhury, et al.) explored the transverse three-point correlation (ζ) of Ly α clouds using mock triplet spectra from simulations at $z \sim 2$ on scales of $1\text{--}5 h^{-1}\text{cMpc}$. They find ζ to depend strongly on N_{HI} , and scale and weakly on angle of the triplet configuration. They show that the "hierarchical ansatz" is applicable for scales $\geq 3h^{-1}\text{cMpc}$, and obtain a median reduced three-point correlation (Q) in the range 0.2-0.7. They show that ζ is influenced strongly by the thermal and ionization state of the gas. As in the case of galaxies, the influence of physical parameters on Q is weaker compared to that on ζ . They also show that difference in ζ and Q between different simulations are minimized if they use appropriate N_{HI} cut-offs corresponding to a given baryon over-density (Δ) using the N_{HI} vs Δ relationship obtained from simulations. They study the effect of pressure broadening on ζ using a model with artificially boosted heating rates. However, for models with realistic thermal and ionization histories, the effect of pressure broadening on ζ is sub-dominant compared to other local effects. They find the strong redshift evolution shown by ζ , mainly originating from the redshift evolution of thermal and ionization state of the IGM. They also estimated the observational requirements for the detection of three-point correlation, specifically, in small intervals of configuration parameters and redshift.

Optically thin C III absorbers

Metallicity and physical state can be probed by the ionization modelling of metals in the IGM. **Raghunathan Srianand**, and his collaborators (Abhisek Mohapatra, and Ananta C. Pradhan) have presented a detailed analysis of 99 optically thin C III absorption systems at redshift $0.2 \leq z \leq 0.9$, associated with neutral hydrogen column densities in the range $15 \leq \log N(\text{HI})(\text{cm}^{-2}) \leq 16.2$. Using photoionization models constructed using CLOUDY, they infer the number density (n_{H}), C-abundance ($[\text{C}/\text{H}]$), and line-of-sight thickness (L) of these systems in the ranges $-3.4 \leq \log n_{\text{H}}(\text{cm}^{-3}) \leq -1.6$, $-1.6 \leq [\text{C}/\text{H}] \leq 0.4$, and $1.3 \text{ pc} \leq L \leq 10 \text{ kpc}$, respectively, with most of the systems having sub-kpc scale thickness. They combine the low- z and previously reported high- z ($2.1 \leq z \leq 3.3$) optically thin C III systems to study the redshift evolution and various correlations between the derived physical parameters. They find a significant redshift evolution in n_{H} , $[\text{C}/\text{H}]$, and L , and compare the redshift evolution of metallicity in C III systems with those of various types of absorption systems. The slope of $[\text{C}/\text{H}]$ versus z for C III absorbers is steeper compared to the redshift evolution of cosmic metallicity of the damped Ly α sample but consistent with that of sub-DLAs. The existence of strong anti-correlation between L and $[\text{C}/\text{H}]$ for the combined sample with a significance level of 8.39σ . They presented the evidence for the occurrence of two distinct $[\text{C}/\text{H}]$ branch C III populations (low- $[\text{C}/\text{H}]$ branch, $[\text{C}/\text{H}] \leq -1.2$, and high- $[\text{C}/\text{H}]$ branch, $[\text{C}/\text{H}] > -1.2$) in the combined C III sample when divided appropriately in the L versus $N(\text{C III})$ plane. Further studies of C III absorbers in the redshift range $1.0 \leq z \leq 2.0$ are im-



portant to map the redshift evolution of these absorbers and gain insights into the time evolution physical conditions of the circumgalactic medium.

uGMRT search for cold gas at $z \sim 1.0 - 1.4$ towards red quasars

Raghunathan Srianand, Neeraj Gupta, and collaborators (Rajeshwari Dutta, and Ravi Joshi) have presented results of their search for H I 21-cm and OH 18-cm absorption at $z \sim 1.0 - 1.4$ towards red quasars showing strong Mg II absorption using upgraded Giant Metrewave Radio Telescope (uGMRT). The quasars J1501+1822 and J1521 + 5508 show multiple strong associated Mg II absorption at $z \sim 1.1$ and signature of reddening in their optical spectra. They reported the detection of H I 21-cm absorption towards J1521+5508 at the systemic redshift of the quasar, with $N(\text{H I}) = (1.2 \pm 0.2) \times 10^{20} \text{ cm}^{-2}$ for spin temperature of 100 K and unit covering factor. The H I 21-cm absorption is offset from the blueshifted strong Mg II absorbers by $\geq 1500 \text{ km s}^{-1}$. They do not detect H I 21-cm absorption at the redshift of the associated Mg II absorption and at the systemic redshift towards J1501+1822. They argue that lack of one-to-one correspondence between Mg II and H I 21-cm absorption could be related with clumpiness of the neutral gas and the radio and optical sightlines probing different volume of the gas. The presence of strong associated Mg II absorption and reddening in the optical spectra of the quasars lead to an increased detection rate of associated H I 21-cm absorption at $z \geq 1$. They also report non-detection of intervening OH absorption ($[\text{OH}]/[\text{H I}] \leq (1 - 4) \times 10^{-8}$) at $z = 1.3$ towards two red quasars, J0850+5159 and J0852+3435, which show strong metal and H I 21-cm absorption and the 2175 *Angstrom* dust extinction bump.

Ly α emission from a powerful radio galaxy M151304.72-252439.7 at $z = 3.132$

Traditionally, studies of the CGM and IGM have been carried out using absorption lines detected against bright background sources, typically bright quasars. The one-dimensional nature of absorption line studies, however, is not ideal for probing the spatial distribution of the gas surrounding individual galaxies. Despite several studies dedicated to understand the complex interactions between gas surrounding the host galaxies and the galaxies themselves, very little progress has been made to date. In order to fully characterise the physical and kinematic properties of this gas, it is important to combine absorption and emission studies. In particular, detection of extended Ly α emission around AGNs allows one to probe environments of the AGNs.

Recently, **Gitika Shukla, Raghunathan Srianand, Neeraj Gupta**, and collaborators (Patrick Petitjean, Andrew J. Baker, et al.) reported the detection of a large ($\sim 90 \text{ kpc}$) and luminous Ly α nebula [$L_{\text{Ly}\alpha} = (6.80 \pm 0.08) \times 10^{44} \text{ erg s}^{-1}$] around an optically faint ($r > 23 \text{ mag}$) radio galaxy M1513-2524 at $z_{\text{em}} = 3.132$ (see Figure 3). The double-lobed radio emission has an extent of 184 kpc, but the radio core, i.e., emission associated with the AGN itself is barely detected. This object was found as part of the survey to identify high- z quasars based on Wide-field Infrared Survey Explorer (WISE) colours. The optical spectrum has revealed Ly α , N V, C IV, and

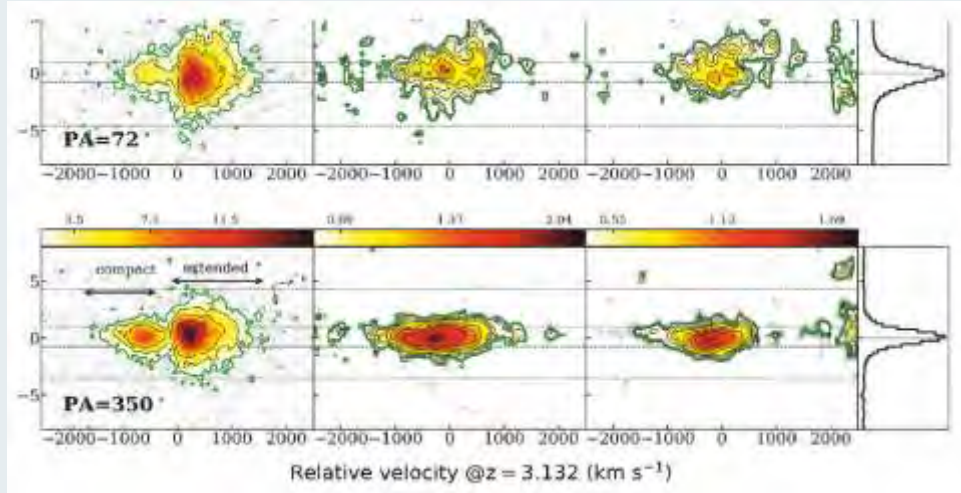


Figure 3: 2D spectra of M1513-2524 obtained with long-slit oriented along 2 PAs. The upper panel corresponds to PA=72°, and the lower to PA=350°. In both rows, the first, second and third columns are for, C IV and He II emission, respectively. The fourth column is the normalized SPSF corresponding to each PA.

He II emission lines with a very weak continuum. Based on long-slit spectroscopy and narrow band imaging centred on the Ly α emission, they identify two spatial components: a “compact component” with high velocity dispersion ($\sim 1500 \text{ km s}^{-1}$) seen in all three lines, and an “extended component”, having low velocity dispersion (i.e., $700\text{-}1000 \text{ km s}^{-1}$). The emission line ratios are consistent with the compact component being in photoionization equilibrium with an AGN. They also detect spatially extended associated Ly α absorption, which is blueshifted within $250\text{-}400 \text{ km s}^{-1}$ of the Ly α peak. The probability of Ly α absorption detection in such large radio sources is found to be low ($\sim 10\%$) in the literature. M1513-2524 belongs to the top a few per cent of the population in terms of Ly α and radio luminosities. Deep integral field spectroscopy is essential for probing this interesting source and its surroundings in more detail.

Multiphase quasar outflows in $z = 2.631$ quasar J001514+184212

Raghunathan Srianand, Neeraj Gupta, and collaborators (Pasquier Noterdaeme, Sergey A. Balashev, Jens-Kristian Krogager, et al.) have presented ultraviolet to near infrared spectroscopic observations of the quasar SDSS J001514+184212 and its proximate molecular absorber at $z = 2.631$. The [O III] emission line of the quasar is composed of a broad (FWHM $\sim 1600 \text{ km s}^{-1}$), spatially unresolved component, blueshifted by about 600 km s^{-1} from a narrow, spatially-resolved component (FWHM $\sim 650 \text{ km s}^{-1}$). The wide, blueshifted, unresolved component is consistent



with the presence of outflowing gas in the nuclear region. The narrow component can be further decomposed into a blue and a red blob with a velocity width of several hundred km s^{-1} each, seen ~ 5 pkpc on opposite spatial locations from the nuclear continuum emission, indicating outflows on galactic scales. The presence of ionised gas on kpc scales is also seen from a weak C IV emission component, detected in the trough of a saturated C IV absorption that removes the strong nuclear emission from the quasar. They observe absorption lines from atomic species in various ionisation and excitation stages and confirm the presence of strong H₂ lines originally detected in the SDSS spectrum. The overall absorption profile is very wide, spread over $\sim 600 \text{ km s}^{-1}$, and it roughly matches the velocities of the narrow blue [O III] blob. From a detailed investigation of the chemical and physical conditions in the absorbing gas, they infer densities of about $n_{\text{H}} \sim 10^4 - 10^5 \text{ cm}^{-3}$ in the cold ($T \sim 100 \text{ K}$) H₂-bearing gas, which they find to be located at ~ 10 kpc distances from the central UV source. They are witnessing different manifestations of a same AGN-driven multi-phase outflow, where approaching gas is intercepted by the line of sight to the nucleus. They corroborate this picture by modelling the scattering of Ly α photons from the central source through the outflowing gas, reproducing the peculiar Ly α absorption-emission profile, with a damped Ly α absorption in which red-peaked, spatially offset, and extended Ly α emission is seen. Their observations open up a new way to investigate quasar outflows at high redshift and shed light on the complex issue of AGN feedback.

Host galaxy of the $z = 3.0091$ DLA

While DLAs are thought to arise from the disks of distant galaxies, it is always difficult to detect the DLA host galaxies. This is mainly because of the faintness of the host galaxies that are expected to be present at a very low impact parameter to the bright quasar sightlines. Recently, **Raghunathan Srianand**, and his collaborators (Ravi Joshi, Michele Fumagalli, Pasquier Noterdaeme, Patrick Petitjean, et al.) have reported the detection of the host galaxy of a DLA with $\log N(\text{H I}) [\text{cm}^{-2}] = 21.0 \pm 0.10$ at $z = 3.0091$ toward the background quasar SDSS J011852+040644 using the Palomar Cosmic Web Imager at the Hale (P200) telescope. They detect Ly α emission in the dark core of the DLA trough at a 3.3σ confidence level, with Ly α luminosity of $L_{\text{Ly}\alpha} = (3.8 \pm 0.8) \times 10^{42} \text{ erg s}^{-1}$, corresponding to a star formation rate of $\geq 2 M_{\odot} \text{ yr}^{-1}$ (considering a lower limit on Ly α escape fraction $f_{\text{Ly}\alpha}^{\text{esc}} \sim 2\%$) as typical for Lyman break galaxies at these redshifts. The Ly α emission is blueshifted with respect to the systemic redshift derived from metal absorption lines by $281 \pm 43 \text{ km s}^{-1}$. The associated galaxy is at very small impact parameter of ≤ 12 kpc from the background quasar, which is in line with the observed anti-correlation between column density and impact parameter in spectroscopic searches tracing the large-scale environments of DLA host galaxies.

High pressure and strong UV field in the DLA towards Q0528-250

Raghunathan Srianand, Neeraj Gupta, and collaborators (Sergey A. Balashev, Cedric Ledoux, Pasquier Noterdaeme, et al.) have revisited the well known asso-



ciated DLA at $z_{abs} = 2.811$ DLA towards Q0528-250 using a very high spectral resolution and high SNR spectra. The enhanced SNR of the spectrum allowed them to detect absorption from the excited fine-structure energy levels of singly ionized silicon (Si II*) and neutral carbon (C I) associated with this H₂ bearing DLA. This absorber has an apparent relative velocity that is inconsistent with the Hubble flow indicating motion along the line-of-sight towards the quasar (i.e., $z_{abs} > z_{em}$). The measured metallicity of this systems is $[Zn/H] = -0.68 \pm 0.02$. Using the relative populations of the fine-structure levels of Si II and C I, as well as the populations of H₂ rotational levels, they constrain the physical conditions of the gas. They derive hydrogen number densities of $n_H = 190^{+70}_{-50} \text{ cm}^{-3}$ and $260^{+30}_{-20} \text{ cm}^{-3}$ in two velocity components where both C I and H₂ are detected. Taking into account the kinetic temperature in each component, $\sim 150 \text{ K}$, they infer high values of thermal pressure in the cold neutral medium probed by the observations. The strengths of the UV field in Draine's unit are $I_{UV} = 10^{+5}_{-3}$ and 14^{+3}_{-3} in each of these two components, respectively. Such enhanced UV fluxes and thermal pressure compared to intervening DLAs are likely due to the proximity of the quasar. The typical size of the absorber is $\sim 104 \text{ au}$. Assuming the UV flux is dominated by the quasar, they constrain the distance between the quasar and the absorber to be $\sim 150\text{-}200 \text{ kpc}$. This favours a scenario where the absorption occurs in a companion galaxy located in the group where the quasar-host galaxy resides. This is in line with studies in emission that revealed the presence of several galaxies around the quasar.

Estimation of CMBR temperature at high- z

The linear increase of the cosmic microwave background (CMB) temperature with cosmological redshift, $T_{\text{CMB}} = T_0(1+z)$, is a prediction of the standard cosmological Λ CDM model. There are, currently, two methods to measure this dependence at redshift $z > 0$. The first method is based on the Sunyaev-Zeldovich (SZ) effect for a galaxy cluster. However, at present, this method is limited to redshifts $z \leq 1$, and only the deviations from the standard relation can be measured with it. In the second method, one uses atomic or molecular excitations. It is now well established by the early work of **Raghunathan Srianand**, and collaborators (Vladimir V. Klimenko, Alexandre V. Ivanchik, Patrick Petitjean, and Pasquier Noterdaeme) that rotational level population of CO molecules at high- z (i.e., $z > 1.5$) DLAs are effective tracers of the temperature of the CMB. Recently, they have presented a new estimates of $T_{\text{CMB}}(z)$ in the redshift range $1.7 \leq z \leq 3.3$ based on the analysis of excitation of the CO rotational levels and C I fine-structure levels in 15 absorption systems. They have carefully taken into account collisional excitation of CO and C I with hydrogen atoms and H₂ molecules and radiative pumping of C I by the interstellar ultraviolet radiation. Applying this corrections leads to a systematic decrease in the previously obtained estimates of $T_{\text{CMB}}(z)$ (for some systems the magnitude of the effect is 10%). Combining these with the measurements of $T_{\text{CMB}}(z)$ in galaxy clusters, they have obtained a constraint on the parameter $\beta = +0.01 \pm 0.013$, which characterizes the deviation of the CMB temperature from the standard relation, $T_{\text{CMB}} = T_0(1+z)^{1-\beta}$, and an independent estimate of the CMB temperature

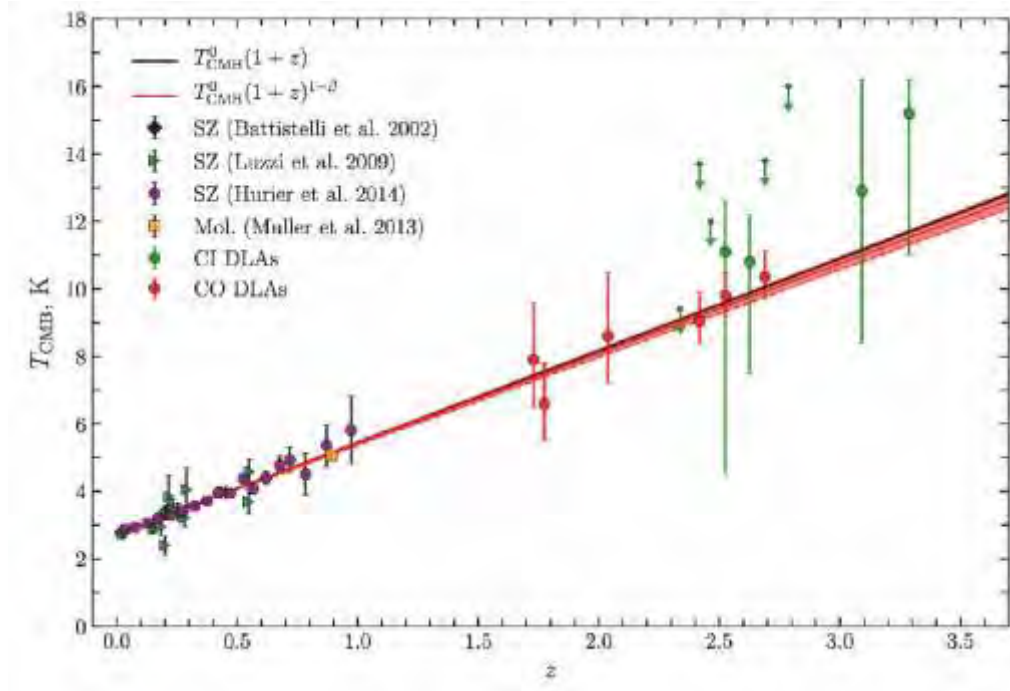


Figure 4: Measurements of the T_{CMB} as a function of z . The green triangles, violet circles, and black diamonds indicate the measurements based on the analysis of the Sunyaev-Zeldovich effect for galaxy clusters (Luzzi, et al. 2009; Hurier, et al. 2014; Battistelli, et al. 2002). The orange square represents the measurements using molecules in a galaxy at $z = 0.89$ (Muller, et al. 2013). The green and red circles represent the measurements in the C I and CO absorption systems in the spectra of quasars. The black solid line indicates the change in CMB temperature according to the standard Λ CDM model. The red dashed line and the shaded region indicate the change in $T_{\text{CMB}}(z)$ with z for an alternative cosmological model $T_0(1+z)^{1-\beta}$ for the parameter $\beta = 0.010 \pm 0.013$.



at the present epoch, $T_0 = 2.719 \pm 0.009$ K, which agrees well with the estimate from CMBR measurements, $T_0 = 2.7255 \pm 0.0006$ K (see Figure 4). This independent estimate is very important because it has been obtained using cosmological data, in contrast to satellite measurements, which are obtained “here” and “now”.

A carbon enhanced absorber: Signature of pop-III stars?

Metal enrichment studies of high- z absorbers provide important insight into the early chemical evolution in the universe. Recently, **Raghunathan Srianand**, and collaborators (Siwei Zou, Patrick Petitjean, Pasquier Noterdaeme, Cedric Ledoux, et al.) have studied an unique high column density absorber at $z_{\text{abs}} = 1.5441$ towards J134122.50+185213.9 observed with VLT X-shooter. This is a very peculiar system with strong C I absorption seen associated with a neutral hydrogen column density of $\log N(\text{H I}) (\text{cm}^{-2}) = 18.10$, too small to shield the gas from any external UV flux. The low-ionization absorption lines exhibit a simple kinematic structure consistent with a single component. Using CLOUDY models to correct for ionization, they find that the ionization parameter of the gas is in the range $-4.5 < \log U < -4.2$ and the gas density $-1.5 < \log n(\text{H}) (\text{cm}^{-3}) < -1.2$. The models suggest that carbon is over abundant relative to iron, $[\text{C}/\text{Fe}] > +2.2$ at $[\text{Fe}/\text{H}] = -1.6$. Such a metal abundance pattern is reminiscent of carbon-enhanced metal-poor stars detected in the galaxy halo. Metal enrichment by the first generation of supernovae provide a plausible explanation for the inferred abundance pattern in this system.

Detection of a Lyman continuum emitting galaxy at $z=1.4$

One of the outstanding problems of current observational cosmology is to understand the nature of sources that produced the bulk of the ionizing radiation after the Cosmic Dark Age. Direct detection of these reionization sources is practically infeasible at high redshift (z) due to the steep decline of intergalactic medium transmission. However, a number of low- z analogues emitting Lyman continuum (LyC) at 900 Angstrom restframe are now detected at $z < 0.4$, and there are also detections in the range $2.5 < z < 3.5$. The redshift range $0.5 < z < 2.5$ has remained barren and has been termed as the LyC desert (See Figure 5). **Kanak Saha**, and collaborators show the first observational detection of a LyC emitting galaxy at redshift $z = 1.42$ by the Ultraviolet Imaging Telescope on board AstroSat. This detection of extreme ultraviolet radiation from a distant galaxy at a restframe wavelength of 600 Angstrom opens up a new window to constrain the shape of the ionization spectrum.

Quasars, AGN and Absorption Systems

Multi-phase medium in the centre of Centaurus A

Multi-wavelength observations of environment of several galaxies have shown the coexistence of multi-temperature region (i.e., the co-spatial existence of hot and cold gas). Theoretically, it is often argued that the presence of multi-phase medium is a natural consequence of phenomenon called Thermal Instability (TI), which operates

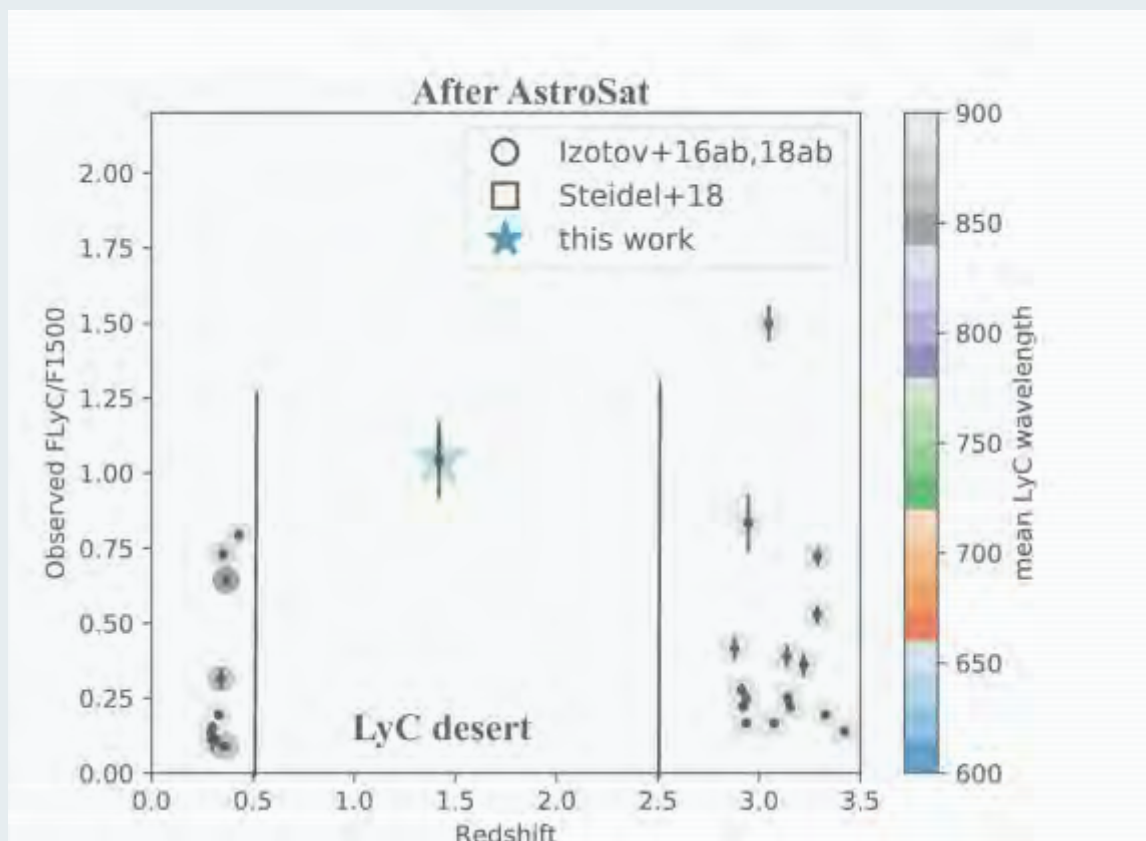


Figure 5: AUDFS01 is the newly discovered galaxy in the LyC desert.

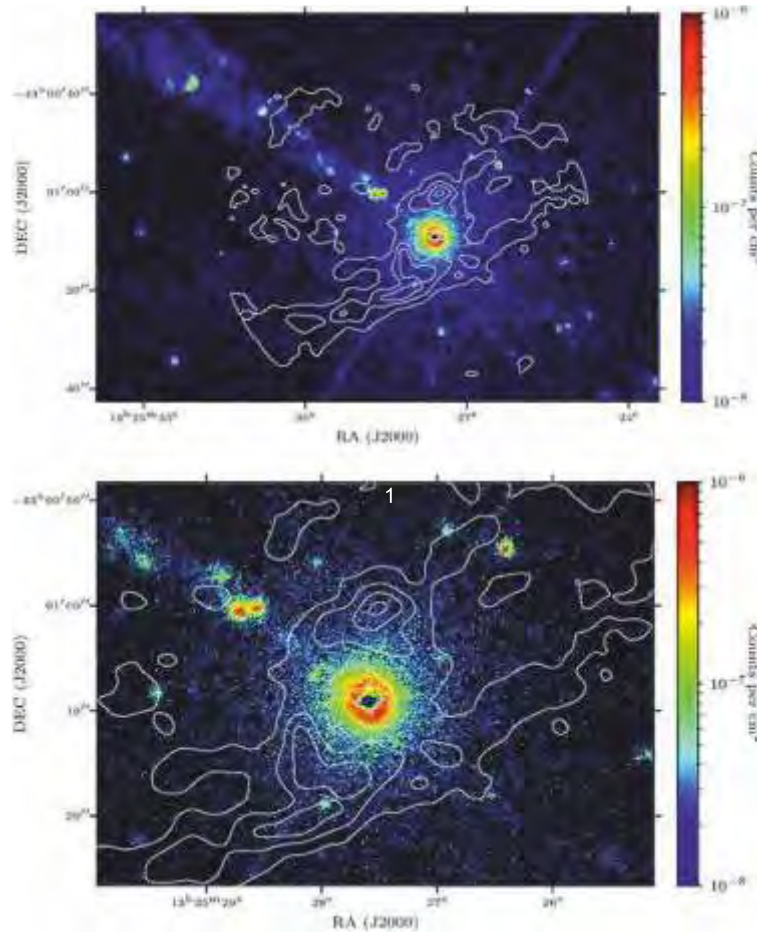


Figure 6: Chandra X-ray images together with *ALMA* contours. The top image shows the central 1 kpc of Cen A in *X-rays*, with overlaid integrated CO (1-0) flux density contours from the *ALMA* main array. The bottom image shows the same, but focused on the central 200 pc region of interest

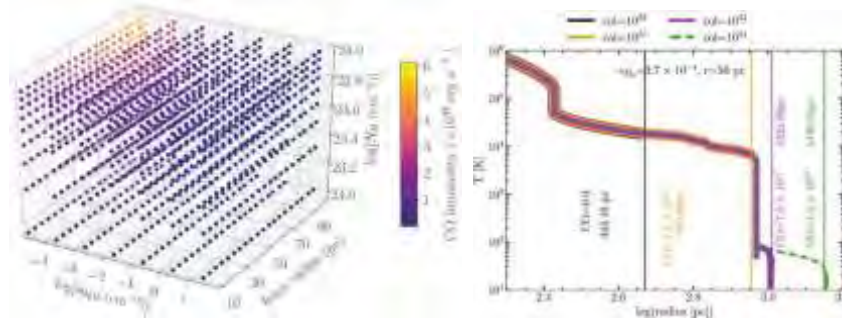


Figure 7: **Left panel:** 3D plot of CO (1-0) line emission derived from photoionization computations as a function of gas density, inner radius, and the column density. It is clear from the figure that the low density - high column dusty gas model favours the observed CO (1-0) emission measured from ALMA. **Right panel:** Length scales of CO (1-0) emission for various column densities are given in the panel box. The model is computed for a gas density 3.7×10^{-4} cm⁻³ located at the inner radius of 10 pc. For each case of cloud thickness, the outer radius is marked by a vertical line. The resulting cloud sizes and CO (1-0) line luminosities are displayed near each vertical line. It is found that in order to reproduce the observed CO line emissivity, the thickness of dusty material should be about 420 pc (22 arcsec), located around 1000 pc (55 arcsec).

when the radiation field from the centre of galaxy interacts with the ambient gas and dust. **Tek P. Adhikari**, and collaborators (Abhijeet Borkar, Agata Rozanska, Alex G. Markowitz, Peter Boorman, et al.) investigated the multi-temperature medium in the vicinity of the AGN Centaurus A (Cen A) by using combined high-resolution observations with the *ALMA* telescope and *Chandra X-ray* observatory. The analysis and comparison of the radio and X-ray images obtained from these observations indicates that the hot X-ray emitting plasma is co-spatial with the warm and cold media in Cen A (Figure 6). The authors utilized the photoionization calculations and verified that the TI is indeed able to generate the multi-phase medium in Cen A, where the hot X-ray phase with temperature $> 10^6$ K stays in pressure equilibrium with the partially ionized gas of temperature 10^4 K that emits the H α spectral line. They demonstrate that cold gas clouds can co-exist in the mutual contact with hot plasma, but even colder dusty molecular clouds have to be distanced by several hundred pc from the central hot region. Finally, the authors propose a 3D model of the appearance of the hot plasma and the CO line-emitting regions consistent with the Chandra image, and derive the emissivity in specific molecular lines observed by *ALMA* from this model (Figure 7 (left)). To reproduce the observed images and the CO line luminosity, the dusty shell has to be 420 pc thick and located at 1000 pc from the center of Cen A (Figure 7 (right)).

Compact steep-spectrum and peaked-spectrum radio sources

Compact steep-spectrum (CSS) and peaked-spectrum (PS) radio sources are powerful extragalactic radio sources associated with galaxies and quasars. These are all < 20 kpc in size with the PS sources being smaller, usually $< \text{few kpc}$. There are three

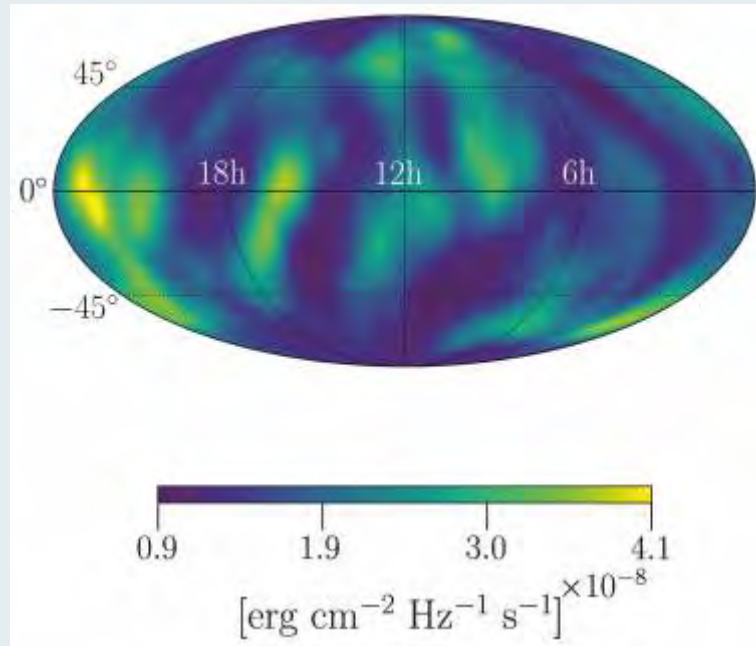


Figure 8: Sky map showing the 95% Credible Level upper limits on gravitational wave energy flux from different directions in the sky for a signal model consisting of mergers of binary black holes and binary neutron stars.

main hypotheses for the nature of PS and CSS sources. (i) The PS sources might be very young radio galaxies which will evolve into CSS sources on their way to becoming large radio galaxies. (ii) The PS and CSS sources might be compact, because these are confined (and enhanced in radio power) by interaction with dense gas in their environments. (iii) Alternately, these sources might be transient or intermittent sources. Each of these hypotheses may apply to individual objects. On an invitation from the Astronomy and Astrophysics Review, Christopher P. O’Dea, and **Dhruba J. Saikia** have reviewed the multi-wavelength properties of these sources, suggested likely scenarios and discussed open questions and prospects for future work.

Gravitational Waves

Search for anisotropies in the gravitational wave backgrounds

One of the major goals of LIGO-Virgo-KAGRA (LVK) gravitational wave (GW) detector network is to detect GW background, which is expected to arise from the superposition of GW signals from many unresolved astrophysical and/or cosmological sources. Generally, these different GW backgrounds are expected to have different frequency dependence, and hence, we might be able to distinguish between them. Apart from the frequency dependence, they can also have spatial features on the sky. For example, since the universe has structures, such as galaxies and galaxy clusters, we expect the sources of GW signals to preferably reside in regions of the sky that contain these structures, giving rise to anisotropies (direction-dependent features) in



the observed GW backgrounds. These anisotropies, if detected, would give us insights into the history of the early universe, and also explain how matter is distributed in the nearby universe. Using data from recently concluded observing runs (O3) of LIGO and Virgo detectors, we searched for anisotropies in the GW background. We did not find any significant evidence in such a background. However, we were able to set stringent upper limits on the strength of GW signals from different directions on the sky (see Figure 8). The team, consisting of members from various institutions in the LVK collaboration, was led by **Shivraj Kandhasamy, Sanjit Mitra, Sanjeev V. Dhurandhar, Sukanta Bose**, and their students and postdocs played key roles over the past two decades in development and advancement of the primary algorithm (the radiometer) used for the search. The new analysis algorithm and the corresponding software (PyStoch) used for most part of the current analysis were primarily developed by the present and past IUCAA researchers under the guidance of **Sanjit Mitra**. Once the LIGO-India detector comes online, these searches will get a significant sensitivity boost and they might be able to detect the anisotropies in GW background.

Unified mapmaking for an anisotropic stochastic gravitational wave background

The LIGO-Virgo collaboration have been putting upper-limits on the anisotropic stochastic gravitational wave backgrounds using data from all past observation runs of the LIGO detectors using the “radiometer algorithm, that uses cross-correlation of data from pairs of detectors with appropriate time dependent phase delays to construct a map of the sky. These upper-limits were being put in the pixel and spherical harmonic bases separately. **Sanjit Mitra** with collaborators (Jishnu Suresh, and Anirban Ain) showed that the results derived in one basis are transformable to the other, as one would expect. They incorporated the spherical harmonic basis analysis in the highly efficient PyStoch pipeline, which they had originally developed for the pixel basis. Moreover, they introduce techniques for fast implementation of the analysis in the spherical harmonic basis, which is useful to derive the Fisher information matrix in that basis necessary for putting upper-limits and showed that the results numerically agree to the conventional method to better than 0.1%. Thus, one unified pipeline will now be able to perform all the standard searches for the stochastic background in an efficient way and enabling comprehensive cross-validation of the results.

Probing hyperons in neutron stars using GWs from f-mode oscillations

Multi-messenger observations (gravitational wave, multi-wavelength electromagnetic observations) of neutron stars (NS) provide us with information rich in physics under extreme conditions. At the ultra-high densities in the NS interior, strangeness-containing matter (e.g., hyperons), which are briefly seen in heavy-ion collision reactions, could appear as stable components of matter. The presence of strange matter will influence the equation of state (EoS) and consequently the observable properties of NSs. Quasi-normal modes, such as f-modes, may be excited in isolated NSs or

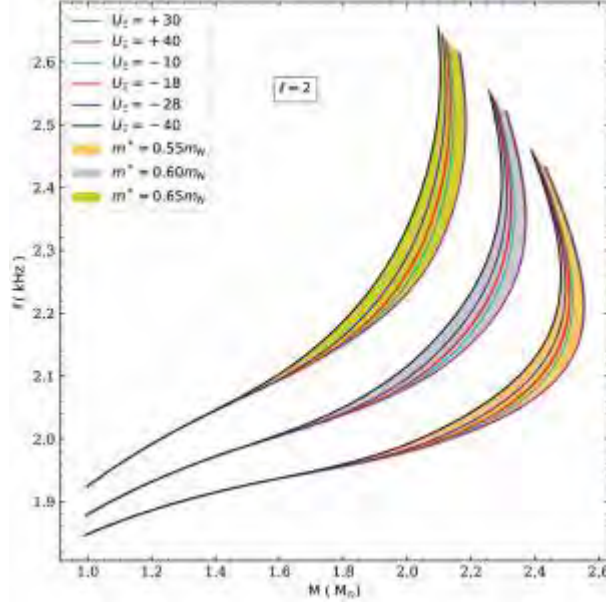


Figure 9: f-mode frequencies as a function of NS mass. Curves with same colour correspond to same Ξ -hyperon potential (hyperon potential with largest uncertainty) in MeV. Set of curves within a shaded area correspond to a fixed value of effective nucleon mass (dominant uncertainty among nuclear saturation parameters).

NS mergers, producing copious amounts of gravitational waves (GW). The frequency and damping times of such modes contain information about the NS core composition. Detection of f-modes would then allow us to invert semi-empirical relations in asteroseismology and impose constraints on the NS EoS.

During his graduate project under the supervision of **Debarati Chatterjee**, **Bikram K. Pradhan** investigated the influence of the appearance of hyperons on f-mode oscillation frequencies, and therefore, on the emission of GWs. They extended a recent sensitivity study of the role of underlying nuclear saturation parameters and their uncertainties (obtained from state-of-the-art nuclear experiments) to include hyperonic degrees of freedom. Their investigation also discussed whether a future detection of f-mode frequencies could provide a possibility of probing the presence of hyperons in the neutron star core. (See Figures 9 and 10).

Gravitational lensing of gravitational waves: Effect of microlens population in lensing galaxies

With increasing sensitivities of the current ground-based gravitational wave (GW) detectors, the prospects of detecting a strongly lensed GW signal are high in the coming years. When such a lensed signal passes through an intervening galaxy or a galaxy cluster, it encounters the embedded stellar-mass microlenses, causing time delays to range from milliseconds to microseconds. These time delays lead to interference patterns that change the GW waveforms morphology and may leave observable signatures. Under the supervision of **Sukanta Bose** and **Anupreeta More**, **Anuj**

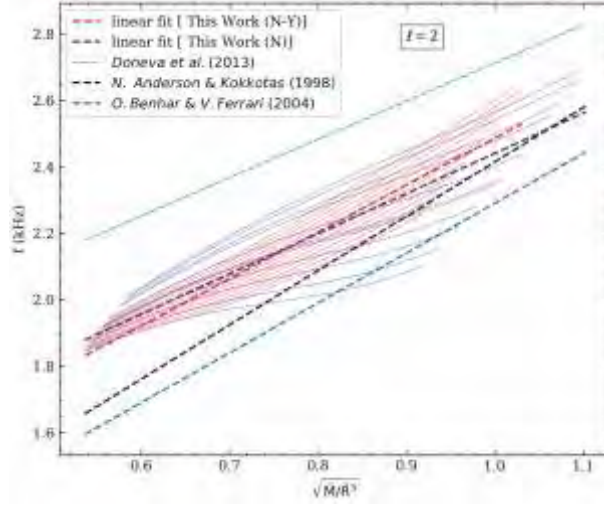


Figure 10: Frequencies for $l = 2$ mode as a function of the average density of the star, for variation in both effective mass and Ξ -hyperon potential. Red solid lines correspond to stars with nucleon-hyperon core and blue solid lines to stars with only nucleonic core. Linear fit relations from this work and other works are shown with dashed lines.

Mishra has conducted an extensive study of how such strongly lensed signals in the LIGO/Virgo frequency range ($10 - 10^4 Hz$) can be affected when microlensed. The methodologies for simulating amplification curves for both minima and saddle images are discussed. A wide range of strong lensing (macro) magnifications and the corresponding surface densities of the microlens population found in lensing galaxies are considered, which are then used to generate realisations of the amplification factor. Effects of parameters like macro-magnifications, stellar densities, the initial mass function (IMF), types of images, and microlens distribution around the source on microlensing are also studied. In general, with increasing macro-magnification values, the effects of microlensing become increasingly significant regardless of other parameters. These investigations, in typical galaxy-scale lens environments, have been carried out for the first time. Mismatch analysis between the lensed and the unlensed GW waveforms suggests that microlensing cannot be neglected for macro-magnification higher than 15. Whereas, for extremely high macro-magnifications > 100 , the effect can be so drastic that we might even miss such signals.

Time-delay interferometry for LISA

With the updated Laser Interferometric Space Antenna (LISA), our current experience with real data from ground-based detectors has shown why it is vital to adopt an approach in which the statistics for performing the data analysis are free from singularities. The algebraic-geometric approach described in the article is inherently singularity free. A seemingly different approach to TDI using matrices has been proposed by other researchers. One of these approaches is termed as TDI-infinity. We have found that it is nothing but the matrix representation of TDI observables - a ring homomorphism - so in principle is no different from the original one. Currently,



Sanjeev V. Dhurandhar, Massimo Tinto, and Prasanna Joshi are investigating the advantages/disadvantages of this approach of using matrix representations.

An optimal chi-square discriminators against noise transients in searches for binary black-hole mergers

The traditional chi-square veto has been applied to the gravitational wave data with fair amount of success. However, this test is ad hoc and is not guaranteed to be optimal. Prasanna Joshi, Rahul Dhurkunde, **Sanjeev V. Dhurandhar**, and **Sukanta Bose** construct an optimal chi-square test for glitches in the data, which can be modelled as sine-Gaussians, because such glitches are ubiquitous in the data. The method for constructing any chi-square has been fully discussed in our previous work. The parameter space of sine-Gaussians is adequately sampled and a vector space spanned by these sampled glitches is obtained. However, this space is very high dimensional and difficult to deal with from the computational point of view. By applying singular value decomposition techniques, it is possible to whittle down this space to a much lower dimensional subspace which best approximates the glitches. This procedure eventually leads to the required optimal chi-square for sine-Gaussian glitches.

Hierarchical search for detecting gravitational waves from compact coalescing binaries (CBC).

Standard searches are currently restricted to the parameter space which assumes aligned spins. A larger parameter space allowing precession will entail far more number of templates escalating the computational cost. **Kanchan Soni**, **Sanjit Mitra**, and **Sanjeev V. Dhurandhar** have implemented a hierarchical strategy to search for CBCs on real data from the science runs O1 and O2. In the first step, a search with a coarse bank at low sampling rate is carried out with a relatively low threshold and then the candidate triggers are followed up with a fine search with the sufficiently high threshold. This method of search is more efficient. They demonstrate a computational advantage of about 20 over the usual search in real data. This saving in the computational cost will allow us to free up computational resources and time.

Cosmic Magnetic Fields

Properties of polarized synchrotron emission from fluctuation-dynamo action - I. Application to galaxy clusters

Using magnetohydrodynamic simulations of fluctuation dynamos, Sharanya Sur, Aritra Basu, and **Kandaswamy Subramanian** perform broad-bandwidth synthetic observations to investigate the properties of polarized synchrotron emission and the role that Faraday rotation plays in inferring the polarized structures in the intracluster medium (ICM) of galaxy clusters. In the saturated state of the dynamo, they find a Faraday depth (FD) dispersion $\sigma_{FD} \approx 100 \text{ rad m}^{-2}$, in agreement with observed



values in the ICM. Remarkably, the FD power spectrum is qualitatively similar to $M(k)/k$, where $M(k)$ is the magnetic spectrum and k the wavenumber. However, this similarity is broken at high k when FD is obtained by applying rotation measure (RM) synthesis to polarized emission from the ICM due to poor resolution and complexities of spectrum in FD space. Unlike the Gaussian probability distribution function (PDF) obtained for FD, the PDF of the synchrotron intensity is lognormal. A relatively large σ_{FD} in the ICM gives rise to strong frequency-dependent variations of the pixel-wise mean and peak polarized intensities at low frequencies (≤ 1.5 GHz). The mean fractional polarization $\langle p \rangle$ obtained at the resolution of the simulations increases from $\langle 0.1$ at 0.5 GHz to its intrinsic value of ~ 0.3 at 6 GHz. Beam smoothing significantly affects the polarization properties below 1.5GHz, reducing $\langle p \rangle$ to ≤ 0.01 at 0.5 GHz. At frequencies greater than 5 GHz, polarization remains largely unaffected, even when recovered using RM synthesis. Thus, their results underline the need for high-frequency (> 5 GHz) observations with future radio telescopes to effectively probe the properties of polarized emission in the ICM.

Small-scale dynamo in supernova-driven interstellar turbulence

Magnetic fields grow quickly even at early cosmological times, suggesting the action of a small-scale dynamo (SSD) in the interstellar medium of galaxies. Many studies have focused on idealized turbulent driving of the SSD. Frederick A. Gent, Mordecai Mark M. Low, Maarit J. Kaplya, and **Nishant K. Singh** simulate more realistic supernova-driven turbulence to determine whether it can drive an SSD, which acts at small eddy scales of turbulence, driving magnetic field growth at correspondingly short timescales. The large-scale dynamo (LSD) with much longer turnover times generates magnetic fields ordered on kiloparsec scales. Hence, capturing LSD alongside the faster growing modes of SSD in simulations is computationally challenging. However, interaction between SSD and LSD modes likely fundamentally determines the evolution and structure of the magnetic field.

They found that the magnetic field growth occurring in their model appears inconsistent with simple tangling of magnetic fields, but consistent with SSD action. Across the modelled range of 0.5 - 4 pc resolution, they found that the SSD saturates at about 5% of kinetic energy equipartition, independent of growth rate. Thus, through the most extensive resolution and parameter study to date, they demonstrated that SSD likely occurs easily in the ISM.

Mean field dynamo action in shearing flows. II: Fluctuating kinetic helicity with zero mean

Naveen Jingade, and **Nishant K. Singh** explored the role of temporal fluctuations in kinetic helicity on the generation of large-scale magnetic fields in the presence of a background linear shear flow. Their model, which includes memory effects and the influence of shear also on the stochastic flow in a self-consistent manner, is successful in predicting a linear scaling (seen in earlier numerical experiments) for the dynamo growth rate with shear at small values of shear rates, purely by temporal fluctuations in the kinetic helicity that are weak enough to avoid any negative turbulent diffusion.



Another important prediction, which appears to be a reasonable expectation, is that the dynamo is quenched when shear becomes too strong. This work is expected to play an important role in understanding the origin of coherent magnetic fields in those systems where the standard alpha-effect is subcritical.

High Energy Astrophysics

Spectropolarimetric analysis of prompt emission of GRB 160325A

The study by **Vidushi Sharma, Shabnam Iyyani, Dipankar Bhattacharya, Tanmoy Chattopadhyay, Santosh V. Vadawale, et al.** of the spectroscopy of GRB 160325A with the Fermi satellite and concurrent polarimetry with the AstroSat-CZTI instrument has revealed that, of the two pulses in this burst, the first one has a mixture of thermal photospheric emission and non-thermal synchrotron emission, while the second one is generated entirely by optically thin synchrotron emission in an ordered magnetic field.

Identifying black hole central engine in gamma ray bursts

The central engine of a gamma ray burst may either be a fast-spinning, strongly magnetized neutron star called a magnetar, or a spinning, accreting, stellar mass black hole. Analysis of the energetics of a large sample of gamma ray bursts has led to the identification of at least eight events in which the total emitted radiative energy exceeds what could be maximally available from a magnetar. These are clear cases of black-hole powered bursts. It was also found that the X-ray light curve of these cases do not exhibit the plateau phase that is often attributed to magnetar-powered emission. This study has been done by **Vidushi Sharma, Shabnam Iyyani, and Dipankar Bhattacharya.**

Time evolution of cyclotron line of Her X-1

AstroSat observations of the X-ray pulsar Her X-1, along with historical observations from multiple missions spanning three decades were used to determine the temporal evolution of its cyclotron line energy, and hence, the apparent magnetic field strength. **Suman Bala, Dipankar Bhattacharya, Ruediger Staubert and Chandreyee Maitra** found that the line energy of the source exhibited a steady decline during 1995-2008 and has been steady since then, indicating a possible equilibrium height achieved by the mound of accretion matter accumulated at the polar cap of the neutron star. This is the first such system where such an analysis has been possible.

Detection of a new cyclotron feature in 4 μ 1700 - 37

In-depth spectroscopic and timing study of a high-mass X-ray binary system 4U1700-37 was carried out by **Suman Bala, Jayashree Roy, and Dipankar Bhattacharya**, using data from AstroSat and NuSTAR missions. A search for periodicity



in the light curve showed no significant detection, while in the energy spectrum a rare Nickel K-alpha emission line was detected at 7.6 keV and the hint of a cyclotron resonance scattering feature was found near 16 keV.

AstroSat observations of the first galactic ULX pulsar

The first ultraluminous X-ray pulsar detected in the Milky Way galaxy, Swift J0243.6+612, was observed with AstroSat during its 2017-2018 outburst. The data revealed pulsations at 9.85 sec period at energies up to 150 keV, with the pulsed fraction increasing towards higher energies. The spectrum observed by Aru Beri, Sachindra Naik, Kuliner P. Singh, **Dipankar Bhattacharya**, **Gulab C. Dewangan**, et al. showed strong evidence of optically thick outflows.

Accretion disks around super-massive black holes

Powering enormous luminosity of Active Galactic Nuclei (AGNs) is thought to be the most efficient and stable engines known in the Universe. The inner regions of accretion disks in AGN are not well understood. **Gulab C. Dewangan**, **Prakash Tripathi**, I.E. Papadakis, and Kulinder P. Singh used the Indian multi-wavelength AstroSat observatory to study a powerful Seyfert 1 galaxy IC 4329A. The Ultra-Violet Imaging Telescope (UVIT) onboard the AstroSat mission provided the highest resolution and deepest images of acquired to date in the far and near UV bands. These data allowed them to accurately separate the extended emission from the host galaxy and the AGN emission, and enabled to derive the intrinsic AGN flux after correcting for the galactic and internal reddening, as well as for the contribution of emission lines from the broad and narrow line regions. The intrinsic UV continuum emission showed a marked deficit compared to that expected from the “standard” models of the accretion disk around an estimated black hole mass of $1 - 2 \times 10^8 M_{\odot}$ when the disk extends to the innermost stable circular orbit. The intrinsic UV continuum is found to be fully consistent with the standard disk models, but only if the disk emits from distances larger than $\sim 80 - 150$ gravitational radii.

AstroSat observation of 2016 burst of H $\sim$ 1743-322

Swadesh Chand, Vivek K. Agrawal, **Gulab C. Dewangan**, **Prakash Tripathi**, and Parijat Thakur detected type C quasi-periodic oscillation (QPO) along with upper harmonic at respective frequencies of ~ 0.6 Hz and ~ 1.2 Hz in a single AstroSat observation taken during the 2016 outburst of the low-mass black hole X-ray binary H $\sim$ 1743-322. These frequencies are found to be shifted by ~ 0.4 Hz for the QPO and ~ 0.8 Hz for the upper harmonic with respect to that found in the simultaneous XMM-Newton and NuSTAR observations taken five days later than the AstroSat observation, indicating a certain geometrical change in the system. However, the centroid frequency of the QPO and the upper harmonic does not change with energy, indicating the energy-independent nature. The decreasing trend in the fractional rms of the QPO with energy is consistent with the previous results for this source in the low/hard state. The photon index of about 1.7 also indicates that the source



was in the low/hard state during this particular observation. In addition, a hard lag of 21 ms in the frequency range of 15 Hz is found similar to the XMM-Newton observations during the same outburst. The log-linear trend between the averaged time lag and energy indicates the propagation of fluctuations in the mass accretion rate from outer part of the accretion disk to the inner hot regions.

Evidence of disc reflection in the X-ray spectrum

Aditya Mondal, Biplab Raychaudhuri, and **Gulab C. Dewangan** studied the broadband X-ray spectrum of the atoll source 4U 1636-536 using NuSTAR observations. The source was found to be in a low-luminosity state during this observation with 3-79 keV X-ray luminosity of $1e37$ erg/s, assuming a distance of 6 kpc. The continuum is well described by a thermal Comptonization model *nthcomp* with photon index of 1.9, electron temperature of 28 keV, and seed photon temperature of about 0.9 keV. The NuSTAR data revealed a clear signature of disc reflection, a significantly broad Fe-K emission line (around 5-8 keV), and the corresponding reflection hump (around 15-30 keV). These reflection features prefer truncated inner disc radii prior to the ISCO. They find that the inner disc is truncated with an inner radius of $R_{in} = 3.2-4.7$ RISCO (16 - 24 gravitation radii or 36 - 54 km). This inner disc radius suggests that the neutron star magnetic field strength is less than about $2e10^9 G$.

UV nuclei or a compact star forming region

Partha P. Deka, **Gulab C. Dewangan**, Kulinder P. Singh, and Joseph Postma reported the discovery of a bright, compact ultraviolet source at a projected separation of 1.1 kpc from the known active galactic nucleus (AGN) in Mrk~766 based on AstroSat/UVIT observations. They performed radial profile analysis and derive the UV flux almost free from the nearby contaminating sources. The new source is about 2.5 and 5.6 times fainter than the AGN in the far and near UV bands. The two sources appear as a pair of nuclei in Mrk~766 and highly unlikely to be another accreting supermassive black hole in Mrk~766 as it lacks X-ray emission. They investigated the nature based on the UV flux ratio, X-ray and optical emission. It is found that the UV/Optical flux measured at four different bands closely follow the shape of the template spectrum of starburst galaxies. Thus, the new source is most likely a compact star-forming region.

Unveiling the broadband spectral and temporal properties of PKS 0903-57 during its brightest flare

Blazars are subclass of active galactic nuclei (AGNs) with powerful relativistic jet pointing close to the line of sight of the observer, which results in extreme properties in the blazar emission. **Zahir A. Shah**, Vadakkumthani Jithesh, Sunder Sahayanathan, and Naseer I. Bhat carried a detailed spectral and temporal study of blazar, PKS 0903-57 using the *Fermi*-LAT and *Swift*-XRT/UVOT observations, during its brightest flaring period MJD 58931-58970. The source reached a maximum daily averaged γ -ray flux of 9.42×10^{-6} ph cm⁻² s⁻¹ in the energy range 0.1-500 GeV



on MJD 58951.5. This is the highest γ -ray flux detected. The authors found that several high-energy (HE) photons (> 10 GeV) were consistent with the source location at high probability ($> 99\%$). They also found that the γ -ray lightcurve in the active state has multiple substructures with asymmetric profile. In order to understand the possible physical scenario responsible for the flux enhancement, the authors carried a detailed broadband spectral study by choosing different flux states from the active period of the source. Neglecting the multi-band variability in each of the selected time intervals, the authors reproduce their averaged broadband SEDs with a one-zone leptonic model whose parameters were derived with a χ^2 -fit. It is found that the broadband SED during different flux states can be reproduced by the synchrotron, synchrotron-self-Compton (SSC), and External-Compton (EC) processes. The seed photons for EC process from BLR or IR torus provide acceptable fits to the GeV spectrum in all the flux states; however, the detection of HE photons together with the equipartition condition suggests that the EC/IR process is a more likely scenario. Further, a detailed comparison between the fit parameters shows that the flux enhancement from quiescent-state to the flaring-state is mostly related to increase in the bulk Lorentz factor of the emission region and change in the break energy of the source spectrum

AstroSat observation of the HBL 1ES 1959+650

Zahir A. Shah, Savithri H. Ezhikode, Ranjeev Misra, and T. R. Rajalakshmi carried a detailed study of X-ray flaring activity of 1ES 1959+650 during October 25-26, 2017 using the AstroSat observations. A maximum X-ray flux of $1.7 \times 10^{-9} \text{ erg cm}^{-2} \text{ s}^{-1}$ was observed. For the first time, a delay between the particle spectral shape and particle density is revealed. The authors investigate the evolution of X-ray spectral properties during the AstroSat observations of the source using the method of time-resolved spectroscopy. They divided the total observation period into time segments of 5 ks, and created SXT and LAXPC spectra for each segment. Each time-resolved spectra were then fitted with a broken power-law convolved with the Synconv model. They found a weak anti-correlation between the index and particle density at zero time lag, a general feature observed in blazars. However, at time delay of about 60 ks, they observed a stronger positive correlation between these parameters. The amplitude of the normalised particle density variation $|\Delta n(\gamma)/n(\gamma)| \sim 0.1$ was found to be less than that of the index $|\Delta \Gamma \sim 0.5|$. The authors model the amplitudes and the time delay in a scenario where the particle acceleration time-scale varies on a time-scale comparable to itself. In this framework, the rest frame acceleration time-scale is estimated to be $\sim 1.97 \times 10^5$ secs and the emission region size to be $\sim 6.73 \times 10^{15}$ cms.

Computational Astrophysics

Simulations of relativistic jet driven feedback

Relativistic jets from supermassive black holes are considered to be an important driver of galaxy evolution. Synchrotron radiation from such jets has been observed in radio frequencies. In order to better understand the dependence of the observed emission on the properties and dynamics of the fluid inside such jets, **Dipanjana Mukherjee**, and his collaborators have performed a set of novel simulations of relativistic jets evolving into the circum-galactic environment. The simulations have used a newly developed numerical module in the PLUTO astrophysical code, that follows the energetics of relativistic non-thermal electrons that emit synchrotron radiation. The simulations cover the dynamics of jets of sizes of ~ 10 kpc, which represent the evolution of young jets that have been freshly triggered by the central super-massive black holes, as shown in Figure 11. The work primarily explores the dynamical

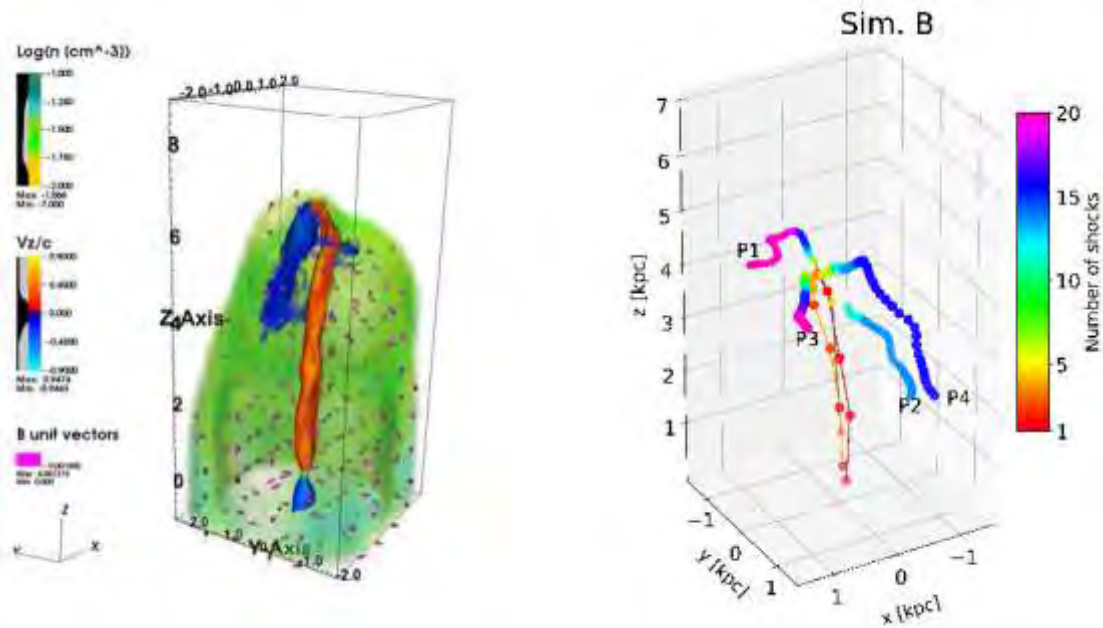


Figure 11: **Left:** 3D volume rendering a simulation of a relativistic jet. The low-power jet ($P \sim 10^{44} \text{ erg s}^{-1}$), shows kink instability, demonstrated by strong bending of the jet-head. The cocoon bubble is depicted in green. The red and blue contours in the central regions denote the jet velocity. The vectors in purple represent the local magnetic field. **Right:** Shows the tracks of a few non-thermal macro-particles, each of which represents a collection of relativistic electrons, with an energy distribution defined by their spectrum. The colour of the particles denote the number of shocks encountered up till the given point in the trajectory. The particles get accelerated at the complex shock near the jet-head and stream downwards with the back-flow.

implications of different MHD instabilities, on the evolution of the jet, and what are their implication for the evolution of non-thermal cosmic ray electrons inside such jets. They have shown how such instabilities can result in internal turbulence in the cocoon, or complex shock structures at the jet-head, which can re-accelerate

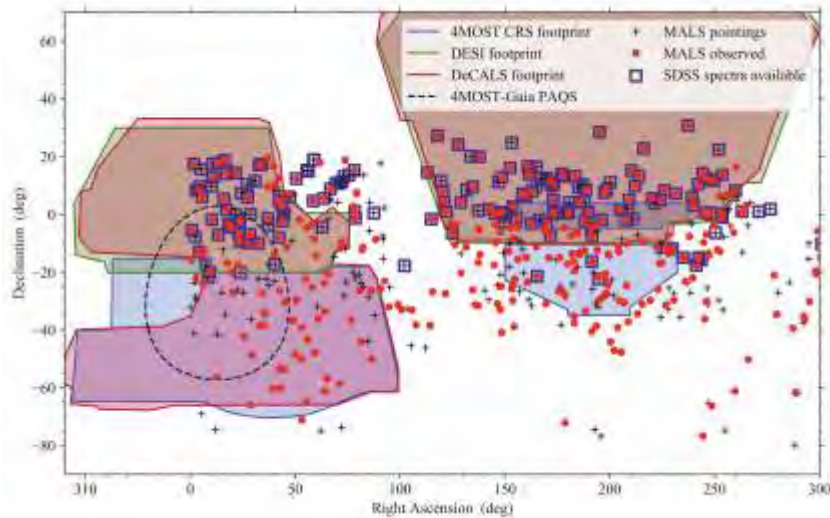


Figure 12: .

cooling electrons. This has significant effect on interpreting the radiative ages of such systems from observations of synchrotron radiation.

The MeerKAT Absorption Line Survey (MALS) gets real !

The MeerKAT Absorption Line Survey (MALS) is one of the ten large surveys being carried out with the MeerKAT radio telescope in South Africa. The MeerKAT array consists of 64 dishes of 13.5m, designed to achieve high sensitivity and imaging dynamic range. Until the Square Kilometer Array (SKA) phase-I is completed, MeerKAT will be the most sensitive telescope at cm wavelengths. Eventually, MeerKAT will be incorporated into SKA phase-I.

MALS consists of 1,655 hrs of MeerKAT time (anticipated raw data ~ 1.7 PB) to carry out the most sensitive search of HI and OH absorption lines at $0 < z < 2$, the redshift range over which most of the evolution in the star formation rate density takes place.

Already, ~ 400 MALS pointings have been observed. The 500 TB of raw visibility data corresponding to these have been transferred to IUCAA. These data are being processed at the specialized data processing and archiving facility set up at IUCAA and released to the survey team in August 2020, and is regularly updated to meet the requirements of the project. The setup consists of Automated Radio Telescope Imaging Pipeline - ARTIP specifically developed for MALS.

ARTIP follows a stage driven architecture, in which outputs from previous stages are used by subsequent stages. At the highest level, it is split into the following four components: ARTIP-CAL, ARTIP-CUBE, ARTIP-CONT, and ARTIP-Diagnostic, which are responsible for calibration, spectral line imaging, continuum imaging, and generating various diagnostic plots and statistics, respectively. The pipeline has been rigorously tested using wideband data from uGMRT, VLA and MeerKAT.

The first uGMRT wideband spectrum is shown in the following figure. Based



on this pilot survey, **Neeraj Gupta, Raghunathan Srianand**, and collaborators estimate the numbers of HI and OH absorbers per unit redshift to be $n_{21}(z \sim 0.18) < 0.14$ and $n_{OH}(z \sim 0.40) < 0.12$, respectively, and constrain the cold gas covering factor of galaxies at large impact parameters ($50kpc < \rho < 150kpc$) to be less than 0.022. Due to the small redshift path, $\Delta z \sim 13$ for H I with column density $> 5.4 \times 10^{19} cm^{-2}$, the survey has probed only the outskirts of star-forming galaxies at $\rho > 30$ kpc. MALS with the expected $\Delta z \sim 10^{3-4}$ will overcome this limitation and provide stringent constraints on the cold gas fraction of galaxies in diverse environments over $0 < z < 1.5$.

The initial MALS science verification observations of the distant gravitationally lensed quasar, PKS1830-211 ($z = 2.51$) have led to the highest redshift detection of OH satellite lines at $z = 0.89$. The previous detection was at $z = 0.25$. The total OH 1720 MHz emission line luminosity is $6,100 L_{\odot}$. This is the most luminous known 1,720 MHz maser line and is also among the most luminous of the OH main line megamasers.

They perform detailed modelling of HI and OH lines detected towards PKS1830-211, and show that while the OH main line ratios are in local thermodynamic equilibrium, the satellite lines require an additional non-thermal component and show conjugate behaviour. Using a lens galaxy model derived from an N-body hydrodynamical simulation, with a morphology similar to its optical HST image, it is shown that the resulting absorption lines depend mainly on the background continuum and the radial distribution of the gas surface density for each atomic and molecular species. It is possible to reproduce the observations assuming a realistic spiral galaxy disk without invoking any central gas outflows. However, there are distinct and faint high-velocity features in the ALMA millimeter absorption spectra that most likely originate from high-velocity clouds or tidal features. These clouds may contribute to the broadening of the H I and OH absorption profiles.

The OH lines can be used as an excellent tracer of diffuse molecular gas as well as dusty/high star forming regions of the Universe. In coming years, MALS will provide an unbiased census of these in the Milky Way halo and external galaxies at $z < 2$. Besides carrying out a sensitive search for intervening HI and OH absorbers, MALS will also provide an unbiased census of intrinsic HI and OH absorbers, that is, cold gas associated with powerful AGNs (radio power $> 1024 WHz - 1$) at $0 < z < 2$, and will simultaneously deliver a blind HI and OH emission line survey and a full-polarization radio continuum survey. The images and catalogues corresponding to these will be released to the MALS team and wider astronomy community through the data processing and archiving setup described above.

Stars, Interstellar Medium and Planetary Studies

Laboratory studies of regoliths – Porosity effects

Numerous atmosphereless minor bodies of our solar system are covered by layers of loosely bound dust particles, which are called regoliths. Light scattered by regolith surfaces is a function of their bulk porosity, their sizes, shapes, structures and

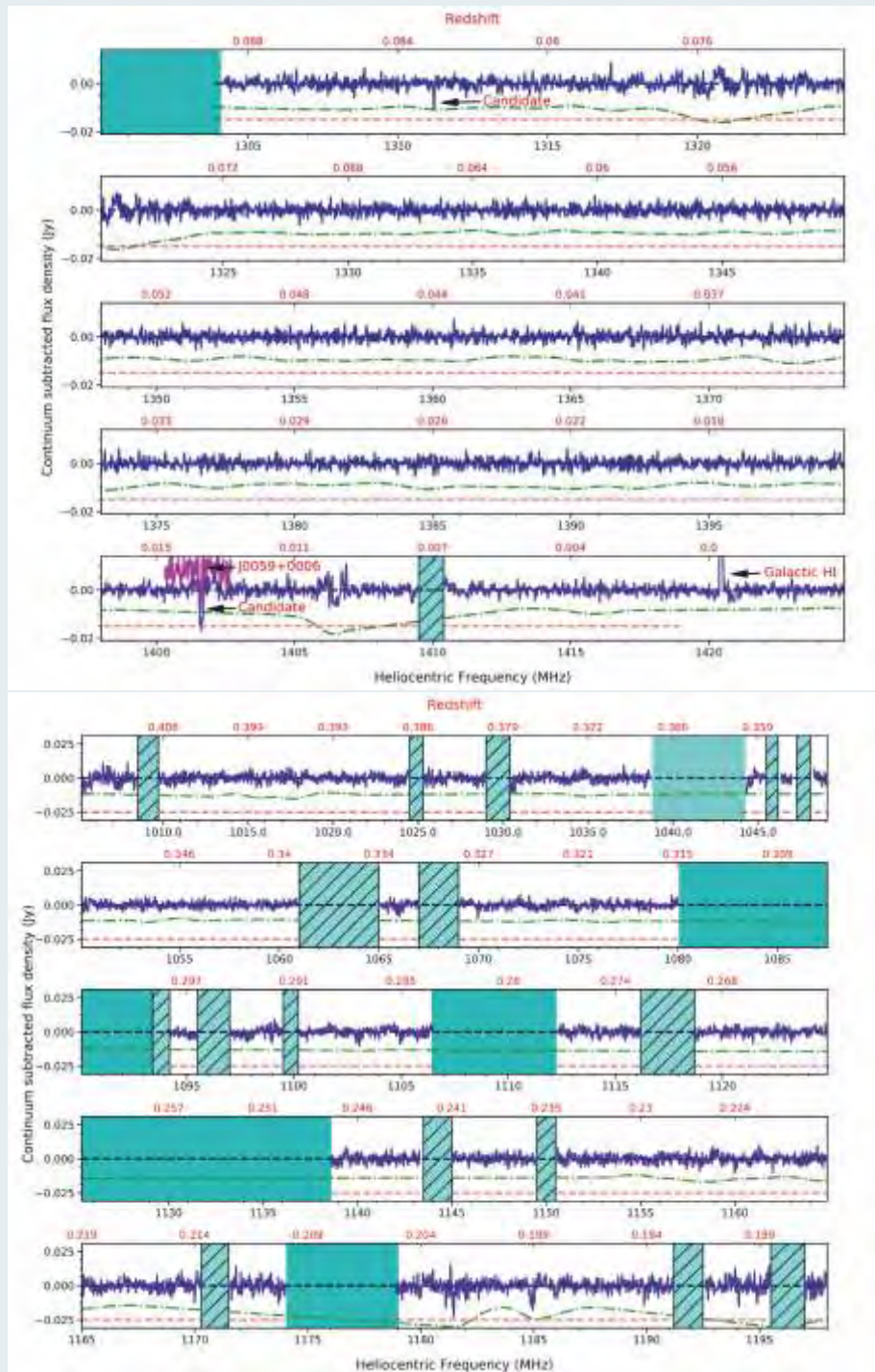


Figure 13: .

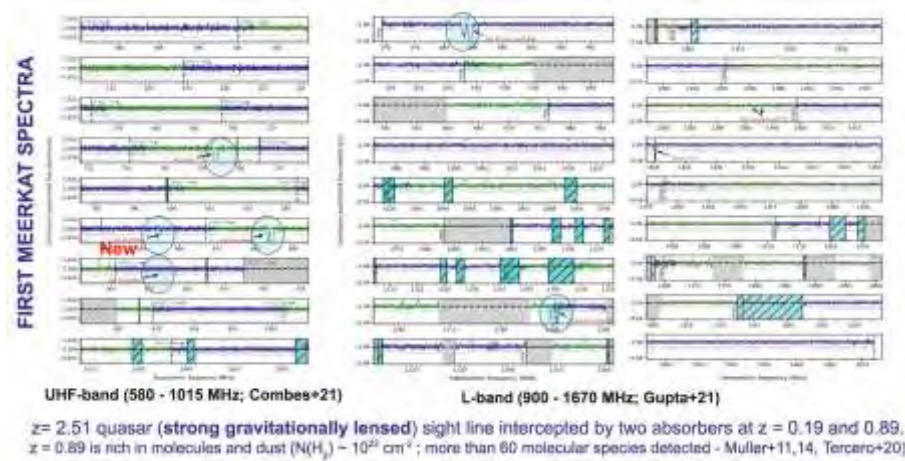


Figure 14: .

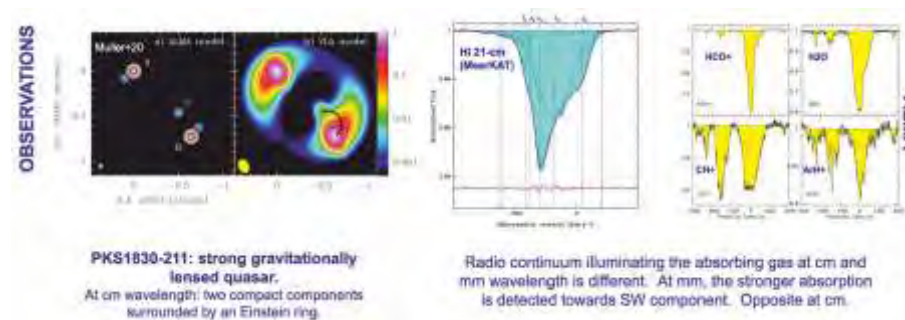


Figure 15: .

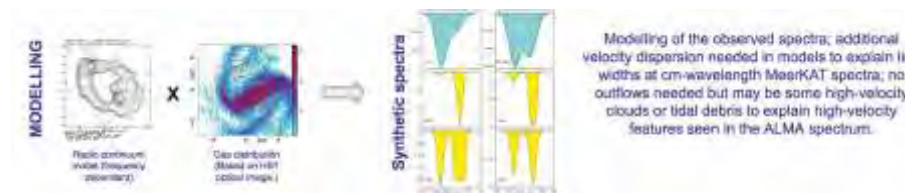


Figure 16: .

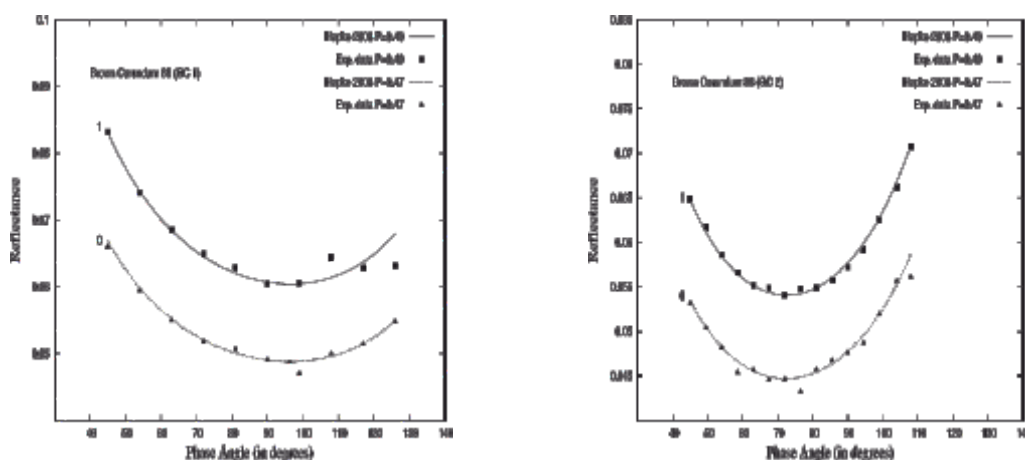


Figure 17: Reflectance of light scattered from rough surface containing 88 μm brown corundum powder having porosity 0.40 and 0.47 under geometrical configurations 1 (left) and 2 (right) are shown as a function of phase angle. The $\blacksquare$ and $\blacktriangle$ represent laboratory data points and solid line represents Hapke's model curve.

compositions of the constituent particles. Laboratory studies of such regoliths have been going on for more than a decade by Asoke K. Sen and his students along with **Ranjan Gupta** using a goniometer developed under IUCAA collaboration.

A set of eight samples including three with industrial origin (brown corundum with three different sizes, silicon carbide and boron carbide) and four with natural origin (olivine, basalt, Martian JSC1 simulant, and Oman desert sand) were considered for the studies as analogues for the regolith surfaces of the minor bodies in the solar system.

The four Figures 17, 18, 19, and 20 show that the Hapke's model could fit the experimental phase curves very well. Among the parameters, the single particle scattering albedo can be deduced, the porosity being a free parameter. These laboratory studies clearly provided a technique through which one can remotely infer the different physical properties of the solar system regoliths, which is very useful for future landing missions on different minor bodies.

The variation of albedo with particle size (and also porosity) can be studied in future by investigating different types of analogues as found on the terrestrial surface, meteorite powder, and even from the dust collected from return space missions. It is to be noted that our experiment is the only one of its kind in the country and only a few such experiments are conducted around the world.

Si IV line ratios in an emerging flux region

Line ratios are considered to be one of the best parameters for diagnosing the physical conditions in astrophysical plasma. The two lines of Si IV ion, formed at 1394 Angstrom and 1403 Angstrom, are observed by the Interface Region Imaging Spectrometer (IRIS). These lines play an important role in characterizing the physical state of the plasma in different features observed in transition region. Under optically thin condition, the ratio of these two lines (1394 Angstrom/1403 Angstrom)

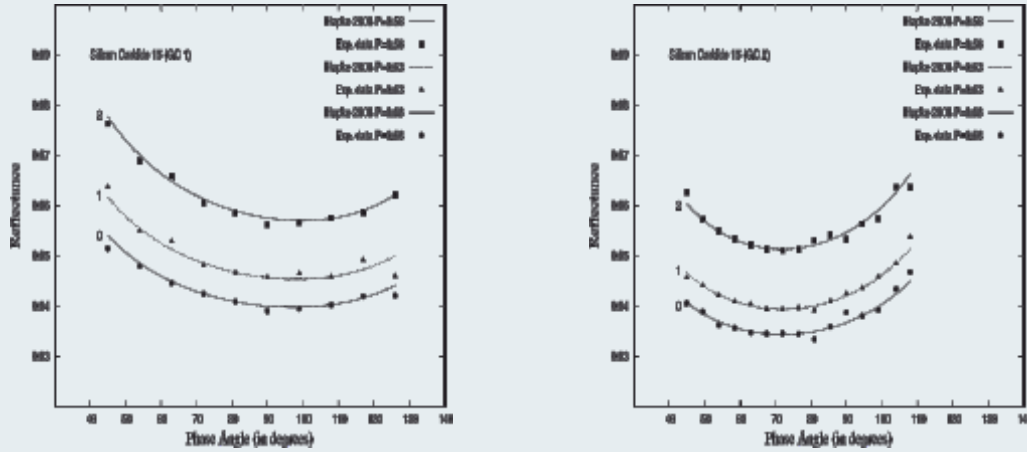


Figure 18: Reflectance of light scattered from rough surface containing 15 μm silicon carbide powder having porosity 0.56, 0.63 and 0.68 under geometrical configurations 1 (left) and 2(right) are shown as a function of phase angle. The ■ and ▲ represent laboratory data points and solid line represents Hapke's model curve.

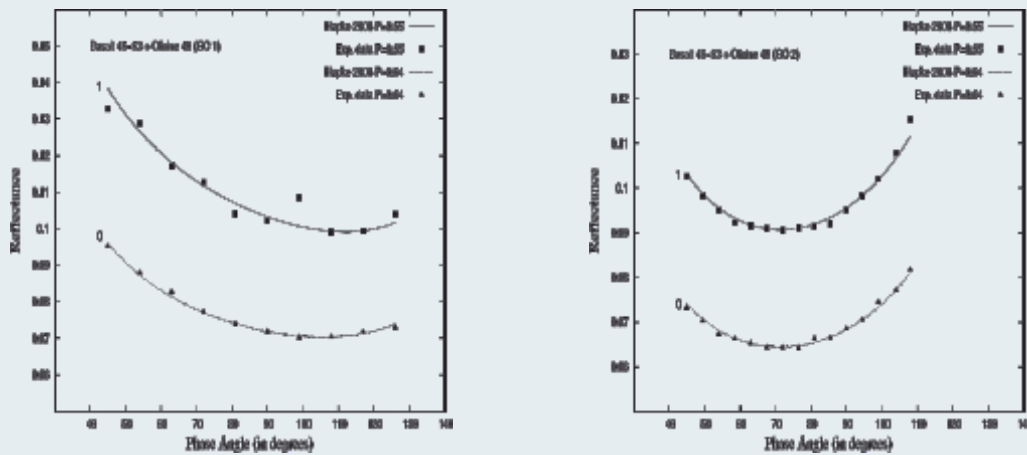


Figure 19: Reflectance of light scattered from rough surface containing 45-53 μm basalt and 49 μm olivine powder (mixed together) having porosity 0.64 and 0.55 under geometrical configurations 1 (left) and 2 (right) are shown as a function of phase angle. The ■ and ▲ represent laboratory data points and solid line represents Hapke's model curve.

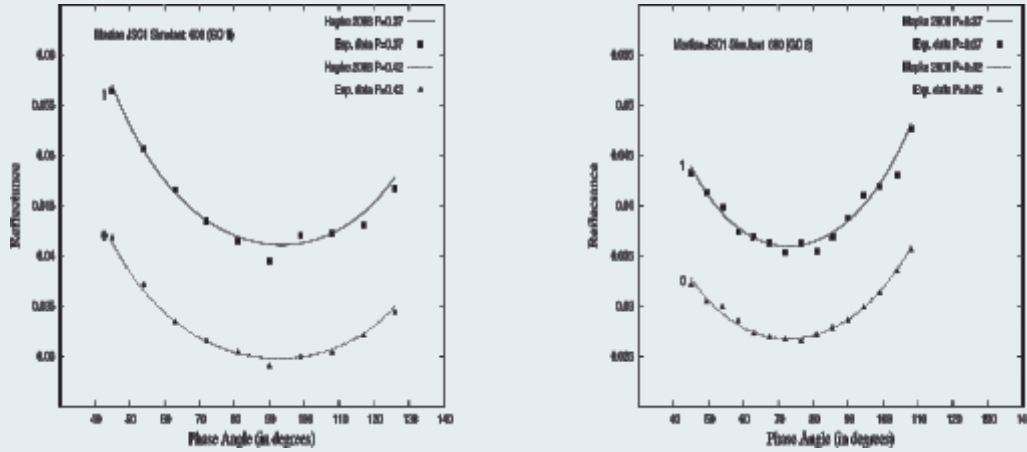


Figure 20: Reflectance of light scattered from rough surface containing Martian JSC1 simulant with size $\sim 600 \mu\text{m}$ powder having porosity 0.37 and 0.42 under geometrical configuration 1 (left) and 2 (right) are shown as a function of phase angle. The $\blacksquare$ and $\blacktriangle$ represent laboratory data points and solid line represents Hapke's model curve.

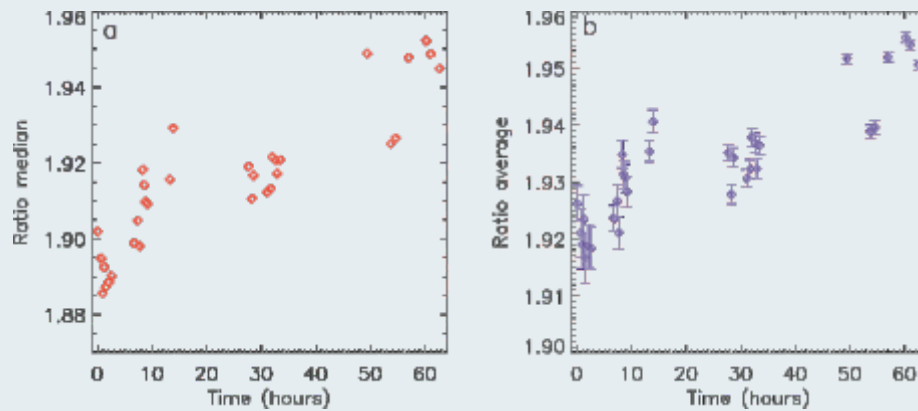


Figure 21: Time evolution of the median and mean of the intensity ratios.



is predicted to be two. Therefore, any departure from this value will suggest that the physics of optically thin plasma cannot be applied. In this work, **Durgesh Tripathi**, and colleagues have studied the emergence and evolution of an active region and studied the time evolution of the ratio of these two lines. Moreover, this ratio has been compared with those obtained for quiet Sun regions. It was found that during the early phase of the development, majority of the regions show ratios smaller than two, and then changes to two as the active region evolves further (see Figure 21). They also found that there were significant amount of regions within the active region that showed ratios larger than 2, which were mostly located within the core of the active region. These findings suggest that the physics of optically thin plasma cannot be applied in the emerging flux regions while studying Si IV lines as they show opacity effects. These results have important implications for the modelling of the solar atmosphere.

Prediction of solar wind speed using deep learning

In order to study the space-weather and its impact, an accurate forecasting of solar wind is of paramount importance. **Vishal Upendran**, and colleagues have used deep learning to forecast solar wind speed as measured near-Earth (L1 point) given solar coronal intensity as seen in extreme-ultraviolet wavelengths. This end-to-end forecasting scheme, based purely on deep learning, outperforms baseline auto-regressive and the standard 27-day persistence model on various metrics (the best-performing correlation was ≈ 0.55). A image showing the observed wind speed (blue), and forecasted wind speed (orange) is given in Figure 22. The vertical bars indicate sudden enhancements in the wind speed.

On investigating the machine learning forecast of “fast” and “slow” winds, the machine was found to “look” at the dark coronal holes 3-4 days prior to forecasting, which is as expected from physics. For the slow wind, the model seems to look at active regions (as expected from the physics), but much closer to the day of forecast. These trends bear an uncanny similarity to the influence of regions potentially being the sources of fast and slow wind, as reported in literature. This suggests that the proposed deep learning model is able to learn some of the salient associations between coronal and solar wind structure without built-in physics knowledge. Such an approach may help discover hitherto unknown relationships in heliophysics data sets.

Untwisting magnetic field in an emerging flux region

Magnetic flux on the Sun emerge at various spatio-temporal scales. In fact, active regions form due to the emergence of magnetic flux. Most of the active regions (about 75%) have certain specific characteristics based on hemispheric helicity rules, and on the solar hemisphere in which they are located. However, why the remaining 25% do not follow such pattern is not well understood. It has been speculated that these 25% active regions are probably in their early phase of emergence. **C. R. Sangeetha**, and **Durgesh Tripathi** with collaborators performed a detailed study of a small emerging bipolar regions. They used space based observations recorded

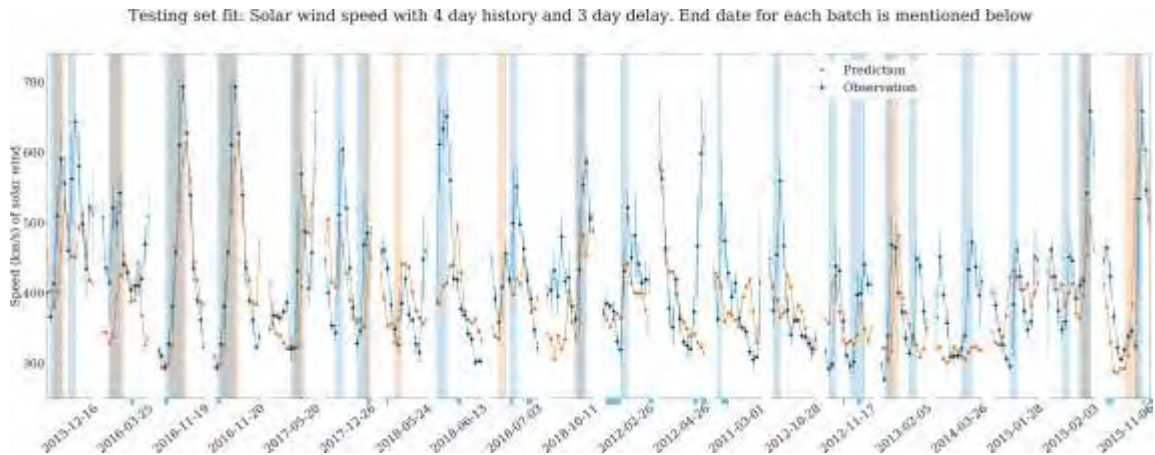


Figure 22: Solar wind speed with 4 day history and 3 day delay. End date for each batch is mentioned on X-axis. Blue colour is observation, and forecasted speed is shown in orange.

from the Helioseismic and Magnetic Imager (HMI) on board the Solar Dynamics Observatory (SDO). To study the flows – both speed and direction – they employed local correlation tracking technique. The results show that during the early phase of the emergence the two magnetic polarities swirl in opposite directions.

In the top panel of Figure 23, the vertical vorticity for leading polarity (black) and trailing polarity (blue) are shown. The plot shows that the leading polarity has negative vorticity (according to the hemispheric rule), whereas the trailing polarity does not. The bottom panel shows the evolution of the unsigned average of the vertical vorticity. These results are indicative of an unwinding of the pre-emergence twist in the magnetic field. They demonstrate the presence of pre-emergence twists in an emerging magnetic field that is important in the context of the hemispheric helicity rule warranting a detailed statistical study in this context. Moreover, the results suggests the possibility of the generation of torsional waves in emerging flux regions due to the untwisting magnetic field with implications for upward energy transport to the corona.

Wave amplitude modulation in fan loops as observed by AIA/SDO

Aishawannya Sharma, Durgesh Tripathi, and collaborators perform a detailed analysis to understand the nature and evolution dynamics of intensity disturbances propagating along fan loops anchored in an isolated sunspot region (see Figure 24). The study carried out using AIA on board SDO shows an increase and decrease in the amplitude of propagating 3-min oscillations over time. Fourier analysis indicates significant power in oscillations within 2-3 minutes, along with many other smaller peaks between 2-4 minutes. Wavelet analysis shows an increase and decrease of 3 min oscillating power simultaneous to the amplitude variations with time, with a mean modulation period in the range of 20-30 minutes (see Figure 25). These results present the viability of occurrence of phenomenon like "Beat" in the solar atmosphere giving rise to the amplitude modulations over time. The observations provide valuable insights into understanding the behaviour and possible coupling of

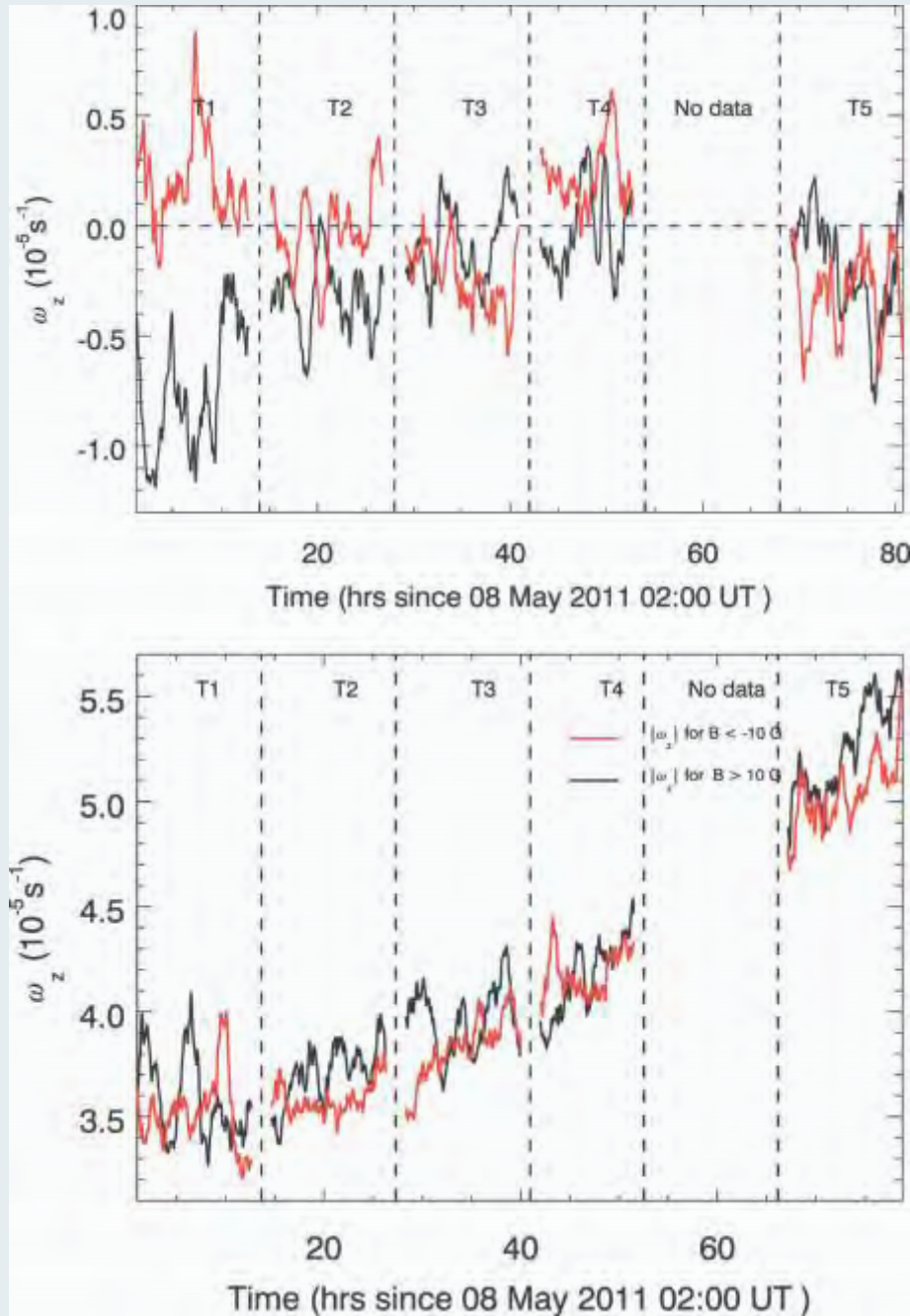


Figure 23: **Top panel:** Evolution of vertical vorticity (spatially signed averaged) for five different sets of observations as labeled for magnetic regions ($\text{abs } (B_{LOS}) > 10 \text{ G}$). The black and red curves show the evolution of signed vorticity for positive and negative magnetic flux, respectively. **Bottom panel:** Evolution of unsigned averaged vertical vorticity.

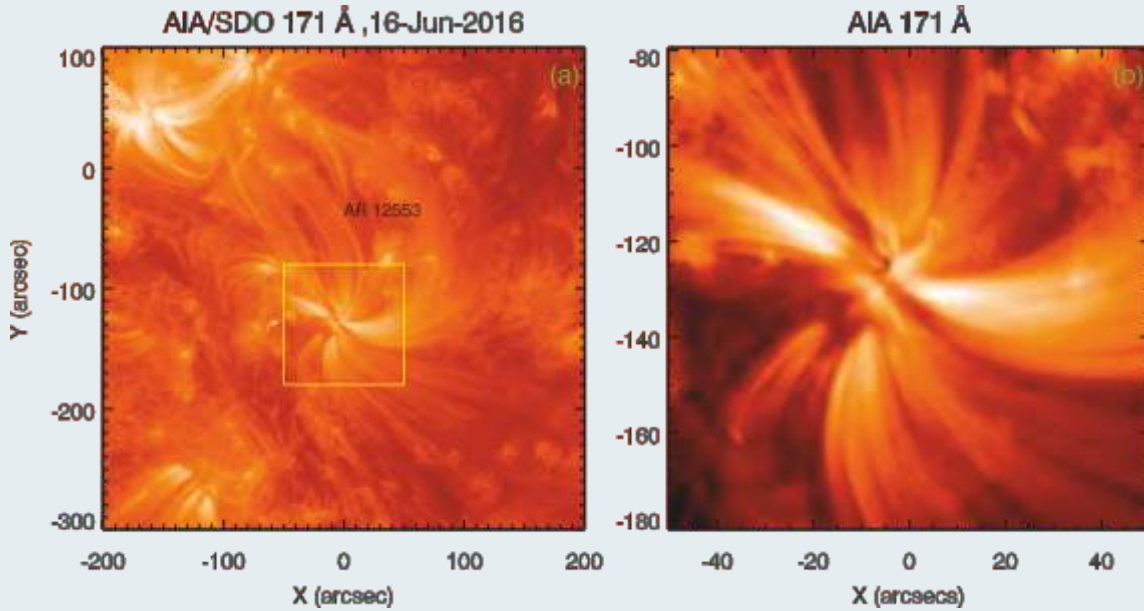


Figure 24: **Left panel:** AIA 171 Angstrom image showing the sunspot and the associated active region. The fan loops are enclosed by the yellow box, which is the region studied. **Right panel:** Zoomed-in image corresponding to the yellow box shown in the left panel.

slow-magnetoacoustic waves propagating along fan loops.

Formation and dynamics of trans-equatorial loops

The solar corona is full of loop structures evolving at various spatio-temporal scales. **Avyarthana Ghosh**, and **Durgesh Tripathi** have studied the dynamical evolution of trans-equatorial loops (TELs) using simultaneous imaging and spectroscopy. The observations are recorded by the Atmospheric Imaging Assembly (AIA) and the Helioseismic Magnetic Imager (HMI) on board the Solar Dynamics Observatory (SDO), in unison with spectroscopic observations taken from the Extreme-Ultraviolet Imaging Spectrometer (EIS) on board Hinode. The imaging data from the AIA 193 Angstrom channel show that TELs are formed between the pre-existing AR 12230 and a newly emerging AR 12234, evolving between 10 - 14 December 2014. The time-distance plots for 12 December 2014, also obtained using AIA 193 Angstrom data, reveal signatures of inflow and outflow towards an X-region (see Figure 26). This is accompanied by recurrent intensity enhancements in close proximity to the X-region (P2), as derived from high-cadence AIA images. At the X-point, the spectral lines that are formed at $\log T[K] = 6.20$ are seen to have higher intensities, whereas the spectral lines at higher temperatures show voids. The electron densities and temperatures in the X-region (and P2) are maintained steadily at $\log Ne = 8.5\text{--}8.7 \text{ cm}^{-3}$ and $\log T[K] = 6.20$, respectively. These observations show the direct interaction of loops and possibly magnetic reconnection within them.

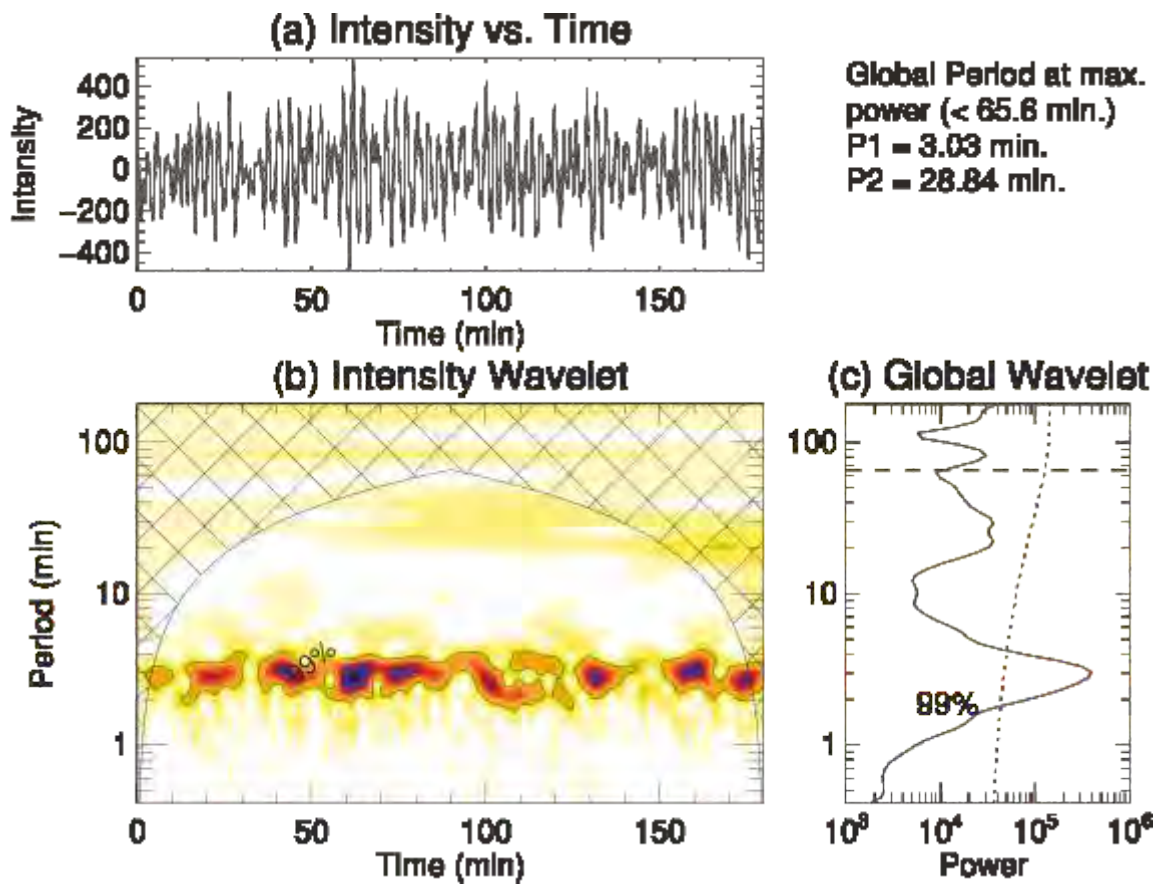


Figure 25: Wavelet analysis results for a detrended light curve obtained at a location on a fan loop. **Top:** The detrended light curve. **Bottom left:** Wavelet spectrum. **Bottom right:** Global wavelet power spectrum. The dashed lines indicate the maximum period detectable from wavelet analysis due to cone-of-influence, whereas the dotted line indicates 99% confidence level curve. Periods P1 and P2 of the first two global power peaks are printed at the top right.

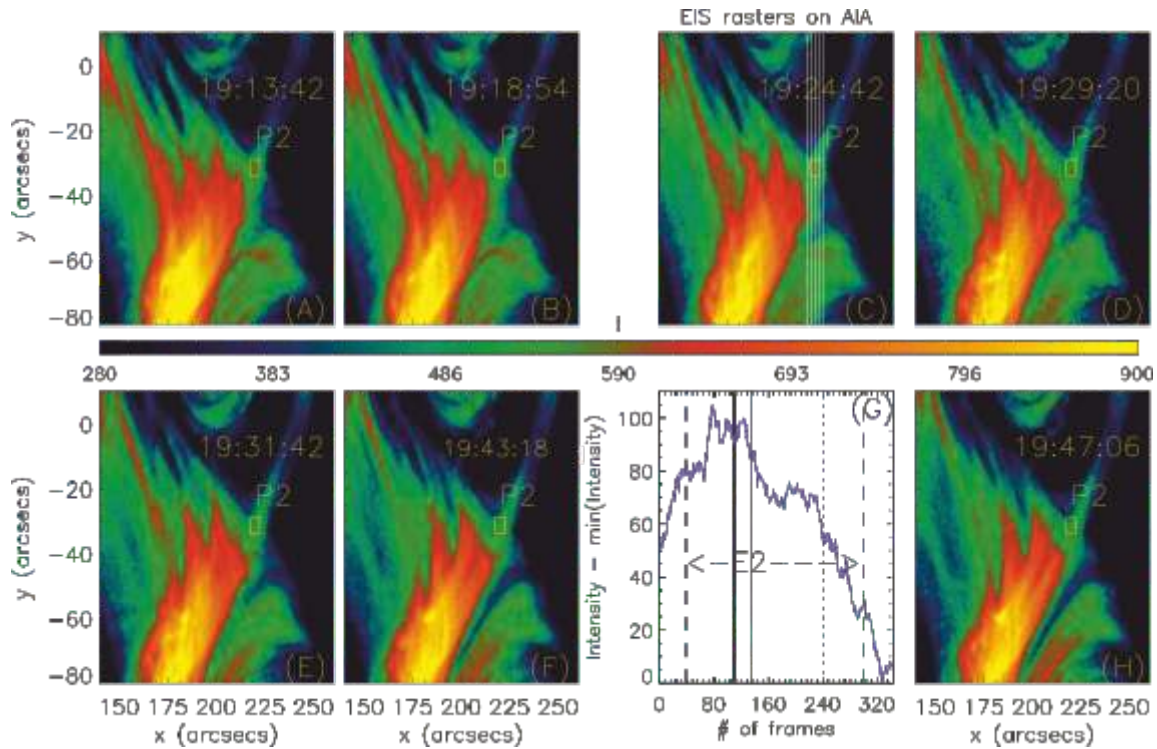


Figure 26: **Panels (A)-(F) and (H)**: AIA ~ 193 ~Angstrom intensity images at different instants which are roughly co-temporal with an EIS observation period (E2). ‘P2’ (highlighted by the yellow box) marks the location for recurrent brightenings. The white vertical lines in panel (C) represent four EIS exposures, which cover at the location of this brightening. **Panel (G)**: Corresponding light curve in box ‘P2’. The dashed vertical black lines represent the exact duration of E2. The black bold lines show the increase in intensity in ‘P2’, which correspond to the EIS exposures shown with white lines in panel (C).



Dynamics of sunspot shock waves in the chromosphere and transition region

Using the observations recorded from IRIS, **Durgesh Tripathi**, and collaborators perform a detailed study of the dynamics of shock waves observed in a sunspot umbra. The shocks are identified by the deformation of spectral line profiles of Mg II, C II, and Si IV ions. The deformation is such that the C II 1335.71 Angstrom and Si IV 1393.75 Angstrom show double-peaked profiles that change to a single peak later on. However, in the beginning, a flat top profile is observed for Mg II h 2803.53 Angstrom, that changes into double peaks followed by the single peak. By a detailed analysis, it was found that in Mg II, shock exhibited both acceleration and deceleration phases. However, only deceleration phase was observed in C II 1335.71 Angstrom and Si IV 1393.75 Angstrom. Moreover, a positive (negative) correlation was found between intensities contributed by the shocks in Mg II and C II (Si IV), which suggested that the shocks may have first amplified in C II, and declined later on in the height range corresponding to Si IV. These results indicate that the dissipation of shocks occurs above the formation height of C II, hence, suggesting an important roles of such shocks in the dynamics of the upper chromosphere and transition region above sunspots.

A unified scenario for coronal heating in quiet Sun and coronal holes and solar wind formation

When observed in coronal images, coronal holes (CHs) are darker than the quiet Sun (QS). While the heating of the solar corona and the acceleration of the solar wind are the two most challenging problems in solar physics, the height of solar wind origin is not known. **Durgesh Tripathi**, and colleagues study the differences and similarities in CHs and QS regions in Si~IV~1394~Angstrom line that forms in the solar transition region. They have used the observations recorded by the Interface Region Imaging Spectrograph (IRIS). For the first time, they have considered the distribution of magnetic field measured by the Helioseismic and Magnetic Imager (HMI) on board the Solar Dynamics Observatory (SDO). The observations show that for regions with identical magnetic flux densities, Si~IV intensities obtained in CHs are lower than those obtained in QS. Moreover, with the increasing flux densities, the difference in intensities increases and QS line profiles are more redshifted than those measured in CHs. It was further observed that, unlike in the QS, the blueshifts measured in CHs showed an increase in magnetic flux density. Although, there is no significant difference in the non-thermal velocities in QS and CHs, it does increase. These results can be explained by a unified model for the heating of the corona in the QS and in CHs and the formation of solar wind. Furthermore, the scenario given by them provides avenues to explain the origin of switchbacks in the magnetic field in the heliosphere, recently observed by the Parker Solar Probe.



Transient formation of loops in the core of an active region

Durgesh Tripathi studies the formation of transient loops in the core of the active region 11890, by using the observations recorded by AIA, HMI and IRIS. The simultaneous observations of the transient in all the UV and EUV channels of AIA and IRIS suggested the multi-thermal nature of the transient, that consisted of short loops (at the base of the transient) and long loops. The multi-thermal nature was further confirmed with a more detailed differential emission measure analysis, which further showed the clumpy structure in the transient. It was found that the transient at its base could achieve a temperature of $\log T = 6.65 - 6.95$. Similar temperature was noted in the long loop too. These results allowed to the conclusion that magnetic reconnection was the primary cause behind the transient. He further proposed that the physics of the formation of these transients may be similar to those of typical coronal jets, albeit in different topological configurations. Such multi-wavelength observations shed light on the formation of hot plasma in the solar corona and provide further essential constraints on modelling the thermodynamics of such transients.

Instrumentation and Calibration

The Ultra-Violet Imaging Telescope (UVIT) onboard AstroSat

AstroSat is India's first UV/X-ray astronomy satellite. The Ultra-Violet Imaging Telescope (UVIT) onboard AstroSat carries two gratings in the FUV channel and a single grating in the NUV channel. These gratings are useful for low resolution, slit-less spectroscopy in the far and near UV bands of a variety of cosmic sources such as hot stars, interacting binaries, active galactic nuclei, etc. **Gulab C. Dewangan** performed the calibration of these gratings using observations of UV standards NGC40 and HZ4, and derived effective areas for different grating orders. The peak effective areas are 18.7cm^2 at 2325 Angstrom for the -1 order of NUV-Grating, 4.5cm^2 at 1390 Angstrom for the -2 order of FUV-Grating1, and 4.3cm^2 at 1500 Angstrom for the -2 order of FUV-Grating2. The FWHM spectral resolution of the FUV gratings is 14.6 Angstrom in the -2 order. The -1 order of NUV grating has an FWHM resolution of 33 Angstrom. There is an excellent agreement in flux measurements between the FUV/NUV gratings and all broadband filters. He has also generated spectral responses of the UVIT gratings and broadband filters that can directly be used in the spectral fitting packages such as XSPEC, Sherpa, and ISIS, thus allowing spectral analysis of UVIT data either separately or jointly with X-ray data from AstroSat or other missions.

SIMULATOR (Speckle Imager via Multi Layer Turbulence Object Reconstruction) is a lab-based instrument designed to mimic a large scale telescope upto 28 m in a small table of size 1 m x 0.5 m. The aim of this experiment is to obtain short time exposed accurate speckle images through the multi-layer 3D atmospheric model. The main purpose of this instrument is to test for alternative techniques to Adaptive Optics, which has been used over the last 70 years, is a complex and very expensive technique in terms of money and resources. **Sorabh Chhabra, A.N.**

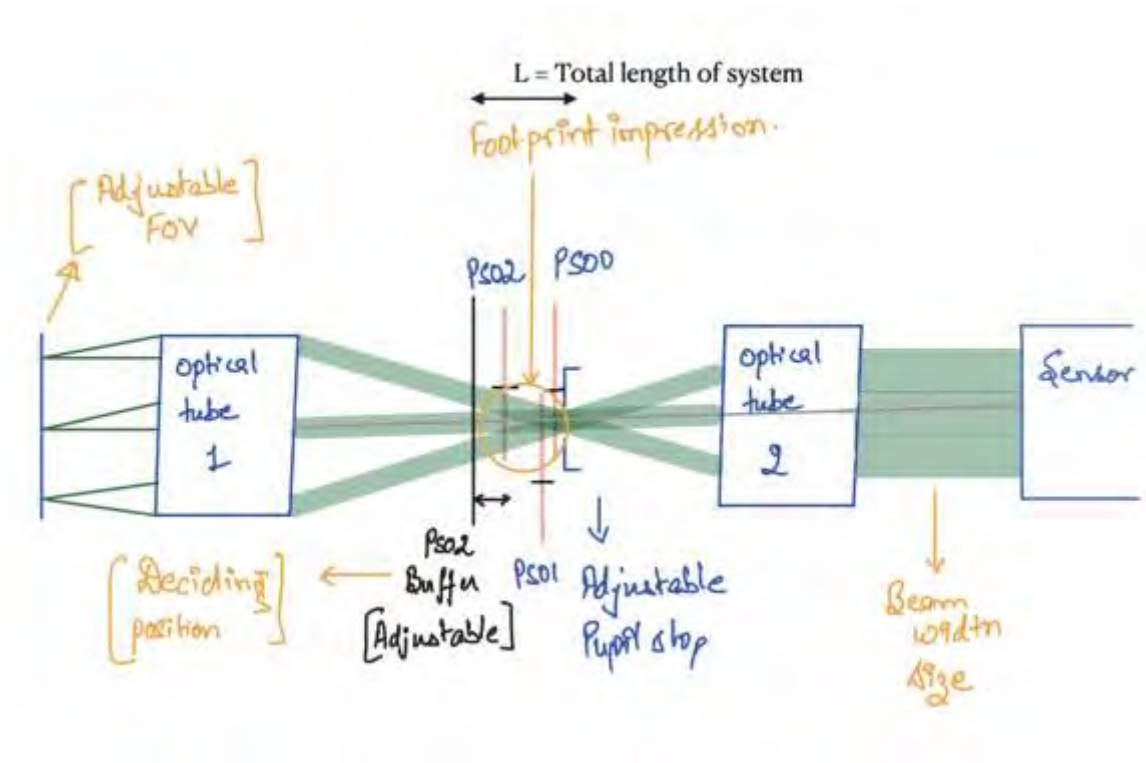


Figure 27: Proposed free hand diagram of SIMULATOR

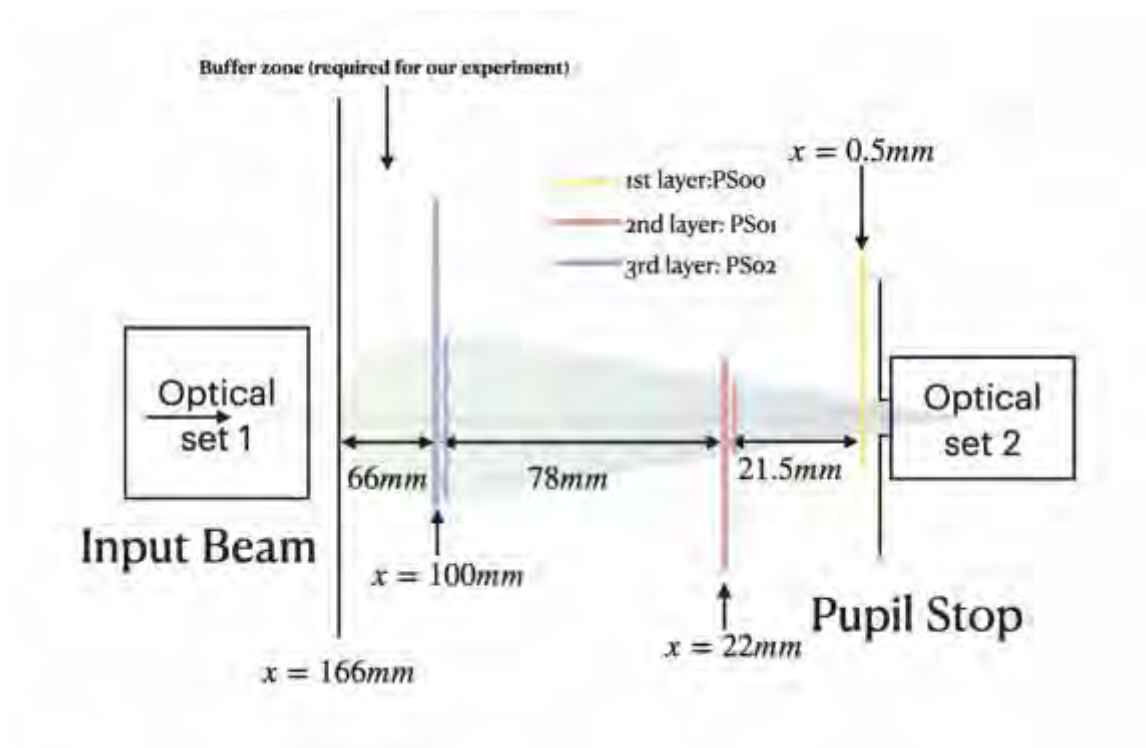


Figure 28: Turbulence phase screen location adjacent to three different layers of the atmosphere.

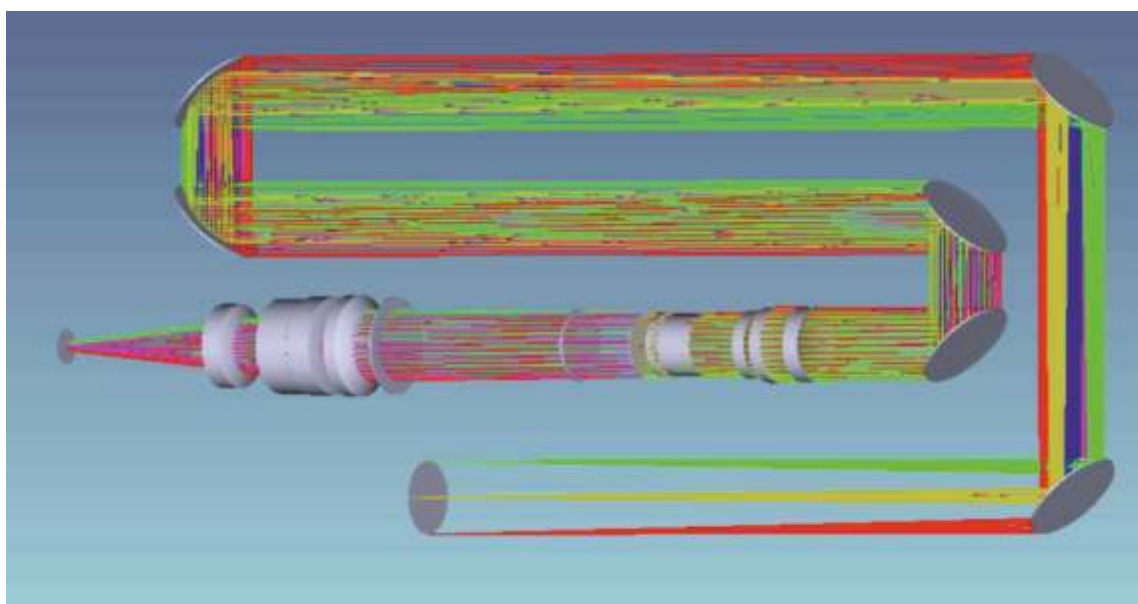


Figure 29: Complete diagram of SIMULATOR from object to camera plane

Ramaprakash, Abhay Kohok, Bhushan Joshi, and Chaitanya V. Rajarshi found out in their simulation a potential method to replace this technique with a much efficient and easy to do approach. (See Figures 27, 28, and 29).

Quantum Technologies

Precision and Quantum Measurement laboratory

The Precision and Quantum Measurement laboratory (<https://pqmlab.iucaa.in/>) at IUCAA is establishing a state-of-the-art experiment based on trapped and laser cooled single ytterbium-ion ($^{171}\text{Yb}^+$) confined in an electrodynamic trap. The highly forbidden $4f146s2S1/2|F=0, mF=0\rangle \rightarrow 4f136s22F7/2|F=3, mF=0\rangle$ octupole (E3) transition of $^{171}\text{Yb}^+$ offers to build one of the most sensitive optical atomic clocks at the 467 nm wavelength. The excited state of this E3-transition has the highest known sensitivity to measure possible breaking of the fundamental symmetries and constancy of the dimensionless fundamental constants. Experimental investigations on these allow to test hypothesis associated with open fundamental questions like, the existence of dark matter and dark energy, matter and anti-matter asymmetry, and many more, which are important to investigate for possible extension of the known standard model and step forward towards grand unification of the four known fundamental forces through a single quantum theory. PQM-lab shall conduct precision measurements for experimental verification of these open fundamental questions, pursue quantum metrology such as geodesy and accurate levelling using optical clocks and develop sophisticated technologies based on quantum phenomena such as chip ion-trap, highly accurate long-distance optical referencing and so on. In order to develop the complex experiment, the main challenge is, the optical

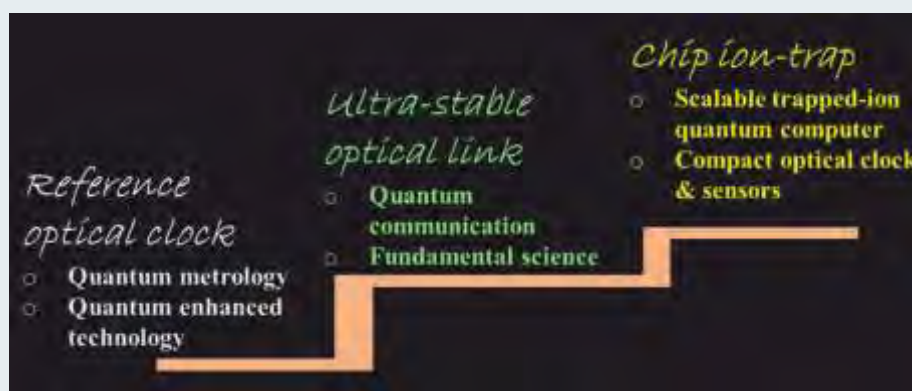


Figure 30: Technologies those are planned to be developed at the Precision and Quantum Measurement laboratory (PQM-lab) shall fulfil its own science goals and shall support to develop a wide variety of sophisticated technologies those are featured under the nationwide quantum missions.

atomic clock and its associated technologies, which need to be built from scratch, that involve complete indigenization of the peripheral technologies. PQM-lab plans to work on three major inter-connecting areas (see Figure 30), which are: (i) establishing lab-based reference optical clock, (ii) establishing ultra-stable optical links to network among distant optical clocks, and (iii) developing chip ion-trap, which in future, can be used to build compact optical clocks and serves as the processor for trapped-ion quantum computing. Even though the instrument is named clock, it measures frequency of the E3-clock transition at 642 121 496 772 645.15 Hz, with an unprecedented accuracy of few tens of mHz.

The ions are confined using oscillating electric fields in a Paul trap. Though trapped, the ions are energetic, which is reduced by laser cooling to a sub-mK temperature. This is 100,000 times lower than they are at room temperature. Upon producing the cold sample confined in their respective traps, the clock transition is probed using light from an ultra-stable and narrow line-width laser, and occurrence of the excitation is ensured by detection of the fluorescence produced in this process. Production of the ultra-stable and narrow line-width laser is another state-of-the-art technology, which uses an ultra-stable reference optical resonator, namely a Fabry-Prot (FP) cavity. Essentially, the stability of this external optical resonator is imprinted on the laser and only a certain optical frequency sustains while oscillating round-trip inside the FP-cavity.

Normal optical fiber communication does work for this, but it involves complex technology to stabilize the length of a long optical fiber to an atomic length scale. This is called phase stabilization of the optical fiber for dissemination of the reference optical photons without losing its phase information and introducing noise to it.

End cap Ion-trap

An ion-trap with end-cap geometry will be employed in our experiment to confine a single ion in a nearly pure quadrupole potential created by it. For this purpose,

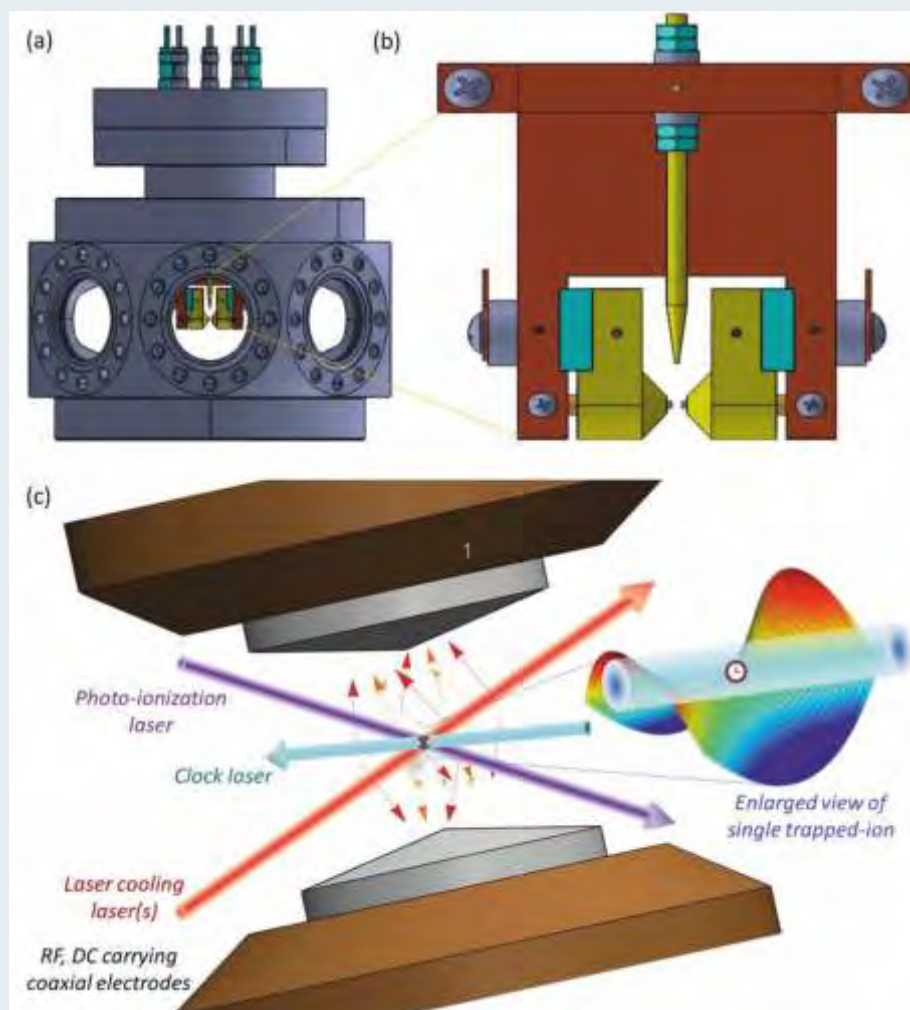


Figure 31: Designs of the (a) ultra-high vacuum housing of the ion trap, (b) end-cap type precision ion trap that to be used to trap single ytterbium-ion to build optical clock, and (c) graphical representation of the single ion confined in an oscillating quadrupole potential and the ion is interacting with multiple lasers for photo-ionization, laser cooling and excitation of the clock transition.

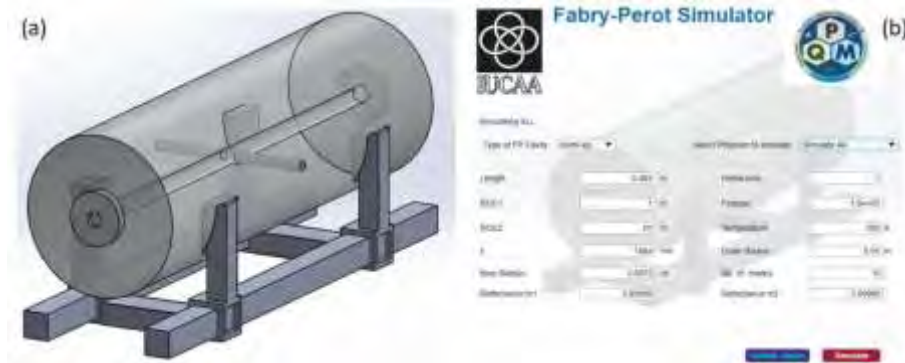


Figure 32: (a) Optimized design of the ultra-stable Fabry-Prot cavity, and (b) the graphical user interface of the developed software that simulates relevant optical parameters those signify quality of a FP-cavity corresponding to a users specified geometry.

elaborate simulations have been performed to identify the most suitable geometric parameter, material selections and thereby minimum systematics induced by the trap itself. Precision machining of the ion-trap and custom design of its ultra-high vacuum (UHV) container, as shown in Figure 31(a,b) are required to meet the critical design parameters. This work is being carried out in collaboration with the team led by Sadiq Rangawala at RRI, Bengaluru to meet the requisites from both our research groups and possibly to a wider community.

Ultra-stable Fabry-Prot (FP) cavity

The above end-cap trap contains a pair of AC carrying electrodes, and each of them is surrounded by DC carrying electrodes made of molybdenum, which are facing towards each other. The ion will be trapped at the centre of the free space available between two AC electrodes. The primary design suggests 0.8 mm diameter rod for the AC electrodes with 1 mm mutual separation between the two opposite ones. The coaxial DC electrode tubes are having 1.4 mm inner and 2 mm outer diameters. For firm mounting of these electrodes inside of an UHV, we have designed a set of holders made of OFHC copper separated by fused silica insulating spacer. The selection of metals depends on good electrical and thermal conductivities, which will lead to desired electric field generation and heat dissipation, respectively. We choose an insulating material having low dielectric loss tangent to reduce the absorption and RF heating of the entire trap assembly, which results in a lower black body radiation shift of the clock transition. Additional to this, a pair of compensation electrodes integrated in the assembly make it more compact and user friendly to mount, which will help us to compensate for the stray electric fields at the centre of the trap. These electrodes are placed at a distance of ~ 5 mm from the RF null that is considered as the centre of the trap. The trap is designed to be assembled on a custom feedthrough with high purity 4 mm diameter copper pins. The whole assembly, that is, the feed through mounted ion trap system will be assembled inside of a commercially available high quality octagonal shaped vacuum chamber having 150 mm outer diameter, through a reducer to match the RF null to the centre of

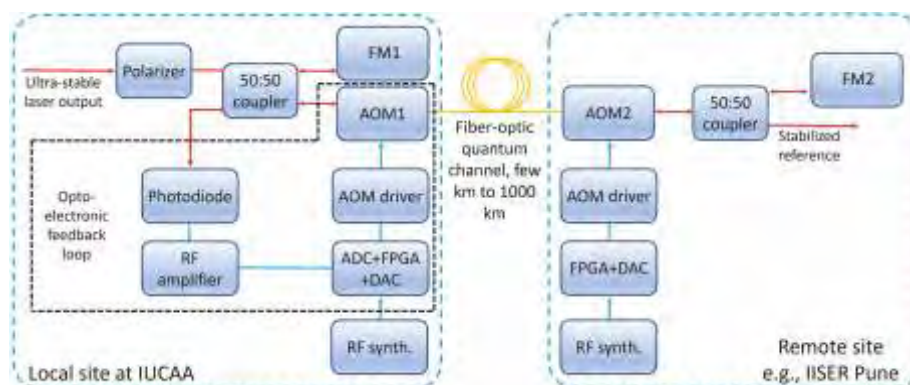


Figure 33: Schematic of the fiber phase stabilization system connecting the optical clocks between two distant locations. AOM1 and AOM2 - acousto-optic modulators, FM1 and FM2 - Faraday mirrors, ADC Analog to digital converter, FPGA Field-programmable gate array, DAC Digital to analog converter, RF synth. Radio-frequency synthesizer.

the chamber. The windows on the octagonal UHV chamber will be closed by anti-reflection coated vacuum compatible sapphire windows except for the one which will be used to connect with the pumping station to reach ~ 10 - 12 mbar inside pressure. A re-entrant view port will be mounted from the bottom of the chamber with a separation of about 20 mm from the RF null, and this view port will be used for high-resolution imaging the single ion. For visualization, an illustration of the single trapped and laser cooled ion is shown in Figure 31(c).

FP-cavity is an essential requirement of the optical clock experiment to produce ultra-stable narrow line width clock laser by transferring stability of the external optical resonator using the Pound-Drever-Hall (PDH) method to the laser. The goal is to achieve a clock laser frequency stability approximately 10^{-17} at 1 s and laser line width on the order of a few hundred mHz.

Subhadeep De, and collaborators have theoretically worked out thermal, gravitational, pressure, vibrational, thermo-mechanical instabilities with different combinations of potential materials for the mirror, spacer, and support that affect the system, as shown in Figure 32(a). They have performed finite element analysis to simulate the thermo-mechanical and gravitational instabilities and currently trying to optimise the parameters to obtain the best design to meet the set goals. Thus, they have developed a software that simulates optical parameters like, mode filtration, mode spacing, mode structure, Brownian noise, etc. of the FP-cavities of different configurations as per the users choice of geometries. This programme will let the users to enter the parameters like length, diameter, radius of curvature of the mirrors, materials properties, etc. into a user-friendly graphical user interface (GUI), as shown in Figure 32(b), which is very useful to select the most optimized choice of a cavity. This work is being pursued in collaboration with the mechanical engineering research group at IIT Goa led by Sandip Haldar.



Phase stabilized optical fiber

Optical clocks are being continuously refined for fractional frequency instabilities of few parts in 10^{18} and lower. The ultra-high accurate comparison of optical clocks separated over long distances uses two way optical fiber time transfer (TWOFTT) technique using phase stabilized optical fibers at the communication wavelength. In the standard optical communication, the fibers suffer from random changes in their length, primarily due to temperature fluctuations, stress and vibration. Such length fluctuations prohibit the photons from being transmitted at a constant phase over the fiber and accumulates phase noise while transmission. This induced phase noise results infrequency broadening of the transmitted light, and hence, cannot be used for precision frequency comparison. Thus, the optical clock comparison requires real-time measurement and cancellation of the random fiber length fluctuations and stabilizing the phase of light transmitted through it. In order to compare two distant optical clocks, the light from an optical clock at the local site (say located at IUCAA) is transmitted over an optical fiber to a remotely located second optical clock (say at IISER Pune). As shown in Figure 33, acousto-optic modulators AOM1 and AOM2 are used to shift the optical frequency by a desired amount. Using Faraday mirror FM2, a portion of the light is reflected to the local site over the same optical fiber via two way communication method. Phases of this light is compared with the light reflected from FM1 at the local site. Any frequency changes in the returning light are representative of the length fluctuations along the optical link. These frequency changes are then corrected in real-time using an opto-electronic feedback loop and a feedback signal is given to the AOM1. The best phase stabilized fiber-optic link exhibits fractional frequency instabilities of 1×10^{-19} , which is an order of magnitude lower than the instability of the clock signal it carries. Therefore, such phase stabilized optical links are able to transmit clock signals over long distances with high fidelity. **Sankalpa Banerjee, Soumyaranjan Jhankar, Stanley Johnson, Ashif Reza, Sankar Majhi, and Subhadeep De** are in the process of developing the requisite technique and the knowledge will be used to build such a fiber phase stabilized link, to serve as a prototype for future optical links for accurate dissemination of optical clock signals in the pan-India.



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144. Ravi Joshi, Michele Fumagalli, **Raghunathan Srianand**, Pasquier Noterdaeme, Patrick Petitjean, et al. (2021) *Discovery of a damped Ly α galaxy at $z \sim 3$ toward the quasar SDSS J011852+040644*, *ApJ*, **908**, 129.
145. Pasquier Noterdaeme, Sergey A. Balashev, Jens-Kristian Krogager, ..., **Raghunathan Srianand**, **Neeraj Gupta**, et al. (2021) *Down-the-barrel observations of a multi-phase quasar outflow at high redshift. VLT/Xshooter spectroscopy of the proximate molecular absorber at $z = 2.631$ towards SDSS J001514+184212*, *A&A*, **646**, A108.
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147. Sharanya Sur, Aritra Basu, and **Kandaswamy Subramanian** (2021) *Properties of polarized synchrotron emission from fluctuation-dynamo action-I. Application to galaxy clusters*, *MNRAS*, **501**, 3332.
148. **Durgesh Tripathi**, V. N. Nived, Hiroaki Isobe, and G. Gerard Doyle (2020) *On the ratios of Si IV Lines ($\lambda 1394/\lambda 1403$) in an emerging flux region*, *ApJ*, **894**, 128.
149. C. R. Sangeetha, **Durgesh Tripathi**, and S. Paul Rajaguru (2020) *Signatures of untwisting magnetic field in a small emerging bipole in the solar photosphere*, *ApJ*, **895**, 67.
150. Pradeep Kayshap, **Durgesh Tripathi**, and Petr Jelínek (2020) *Dynamics of sunspot shock waves in the chromosphere and transition region*, *ApJ*, **906**, 121.
151. **Durgesh Tripathi**, V. N. Nived, and Sami K. Solanki (2021) *Coronal heating and solar wind formation in quiet Sun and coronal holes: A unified scenario*, *ApJ*, **908**, 28.
152. **Durgesh Tripathi** (2021) *Transient formation of loops in the core of an active region*, *ApJ*, **909**, 105.



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(b) PROCEEDINGS

1. **Sorabh Chhabra**, **Jyotirmay Paul**, **A. N. Ramprakash**, and Avinash Surendran (2020) *Gaussian phase auto-correlation as an accurate compensator for FFT-based atmospheric phase screen simulations*, SPIE Procs., Vol. **11448**: Adaptive Optics Systems VII, Editor(s): Laura Schreiber, Dirk Schmidt, and Elise Verent.
2. Neelam Yadav, Harish Rathore, Lakhi Sharma, Atish Roy, ..., **Shubadeep De**, et al. (2020) *Clock comparison with an ultra-stable optical fibre link utilizing White Rabbit Network*, 33rd General Assembly and Scientific Symposium, International Union of Radio Science.
3. Neelam Yadav, M. P. Olaniya, **Shubadeep De**, and Subhasis Panja (2020) *Clock comparison with an ultra-stable optical fibre link utilizing White Rabbit Network*, URSI GASS, Rome, Italy, August 29 – September 5, 2020.
4. Neelam Yadav, M. P. Olaniya, **Shubadeep De**, and Subhasis Panja (2020) *Effect of temperature variation on the stability of an optical fibre based time transfer link*, ITSF-2020, Dusseldorf, Germany, November 2 – 5, 2020.
5. **Sanjeev V. Dhurandhar** (2020) *Black holes in diapers*, Special session in honour of C. V. Vishveshwara, 31st meeting of the Indian Association of General Relativity and Gravitation organised online by IIT, Gandhinagar.
6. **Siddharth Maharana**, ..., **A.N. Ramaprakash**, **Pravin V. Khodade**, **Chaitanya V. Rajarshi**, **Bhushan S. Joshi**, **Pravinkumar A. Chordia**, **Ramya M. Anche**, ..., Tuhin Ghosh, et al. (2020) *WALOP-south: A wide-field one-shot linear optical polarimeter for PASIPHAE survey*, SPIE Procs., Vol. **11447**.
7. Sneha P. Mudambi, Shivappa B. Gudennavar, **Ranjeev Misra**, and S. G. Bubbly (2021) *Spectral characteristics of the black hole X-ray binary 4U 1957+115 using AstroSat and SWIFT*, Procs. 39th Meeting of the ASI, February 18 – 23, 2021.
8. Neal T. Thomas, Shivappa B. Gudennavar, **Ranjeev Misra**, and S. G. Bubbly (2021) *AstroSat's view of the newly discovered soft X-ray transient: MAXI J0637-430*, Procs. 43rd COSPAR Scientific Assembly, Sydney, Australia, January 28 – February 4, 2021.
9. Shivappa B. Gudennavar, Neal T. Thomas, **Ranjeev Misra**, and S. G. Bubbly (2021) *Spectro-temporal variability studies of GX 340+0 using AstroSat*, Procs. 43rd COSPAR Scientific Assembly, Sydney, Australia, January 28 – February 4, 2021.
10. **Kandaswamy Subramanian** (2020) *Origins of cosmic magnetism*, Procs. International Astronomical Union-2018, Astronomy in Focus, **14** (Symposium A30), 291.



c) CIRCULARS AND TELEGRAMS

1. A. Marathe, Vedant Shenoy, Varun Bhalerao, **Dipankar Bhattacharya**, Santosh Vadawale, et al. (2020) *SGR 1935+2154: AstroSat CZTI detections*, GCN Circular No. 27664.
2. Vedant Shenoy, Varun Bhalerao, Igor Andreoni, Mansi M. Kasliwal, **Dipankar Bhattacharya**, et al. (2020) *ZTF20abtxwfx/AT2020sev: AstroSat CZTI non-detection of a transient*, GCN Circular No. 28355.
3. **Soumya Gupta, Vidushi Sharma, Dipankar Bhattacharya**, Varun Bhalerao, A. R. Rao, et al. (2020) *GRB 200403A: AstroSat CZTI detection*, GCN Circular No. 27492.
4. **Soumya Gupta, Vidushi Sharma, Ajay M. Vibhute, Dipankar Bhattacharya**, Varun Bhalerao, et al. (2020) *GRB 200412B: AstroSat CZTI detection*, GCN Circular No. 27563.
5. **Soumya Gupta, Vidushi Sharma, Dipankar Bhattacharya**, Varun Bhalerao, A. R. Rao, et al. (2020) *GRB 200412A: AstroSat CZTI detection*, GCN Circular No. 27588.
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7. **Soumya Gupta, Vidushi Sharma, Dipankar Bhattacharya**, Varun Bhalerao, A. R. Rao, et al. (2020) *GRB 200424A: AstroSat CZTI detection*, GCN Circular No. 27642.
8. **Soumya Gupta, Vidushi Sharma, Ajay M. Vibhute, Dipankar Bhattacharya**, Varun Bhalerao, et al. (2020) *AstroSat CZTI detection: GRB200503A*, GCN Circular No. 27680.
9. **Soumya Gupta, Vidushi Sharma, Dipankar Bhattacharya**, Varun Bhalerao, A. R. Rao, et al. (2020) *GRB 200502A: AstroSat CZTI detection*, GCN Circular No. 27686.
10. **Soumya Gupta, Vidushi Sharma, Dipankar Bhattacharya**, Varun Bhalerao, A. R. Rao, et al. (2020) *GRB 200506C: AstroSat CZTI detection*, GCN Circular No. 27697.
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12. **Soumya Gupta, Vidushi Sharma, Dipankar Bhattacharya**, Varun Bhalerao, A. R. Rao, et al. (2020) *GRB 200510A: AstroSat CZTI detection*, GCN Circular No. 27716.
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24. **Soumya Gupta, Vidushi Sharma, Dipankar Bhattacharya, Varun Bhalerao, A. R. Rao, et al.** (2020) *GRB 200716B: AstroSat CZTI detection*, GCN Circular No. 28118.
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30. **Vedant Shenoy, ..., Soumya Gupta, Vidushi Sharma, Ajay M. Vibhute, Dipankar Bhattacharya, et al.** (2020) *GRB200817B: AstroSat CZTI detection*, GCN Circular No. 28354.
31. **Soumya Gupta, Vidushi Sharma, Ajay M. Vibhute, Dipankar Bhattacharya, Varun Bhalerao, et al.** (2020) *GRB 200903E: AstroSat CZTI detection*, GCN Circular No. 28367.



32. **Soumya Gupta, Vidushi Sharma, Ajay M. Vibhute, Dipankar Bhattacharya**, Varun Bhalerao, et al. (2020) *GRB 200907B: AstroSat CZTI detection*, GCN Circular No. 28395.
33. **Soumya Gupta, Vidushi Sharma, Ajay M. Vibhute, Dipankar Bhattacharya**, Varun Bhalerao, et al. (2020) *GRB 200909A: AstroSat CZTI detection*, GCN Circular No. 28405.
34. **Soumya Gupta, Vidushi Sharma, Ajay M. Vibhute, Dipankar Bhattacharya**, Varun Bhalerao, et al. (2020) *GRB 200916B: AstroSat CZTI detection*, GCN Circular No. 28451.
35. **Soumya Gupta, Vidushi Sharma, Ajay M. Vibhute, Dipankar Bhattacharya**, Varun Bhalerao, et al. (2020) *GRB 200928B: AstroSat CZTI detection*, GCN Circular No. 28526.
36. **Soumya Gupta, Vidushi Sharma, Ajay M. Vibhute, Dipankar Bhattacharya**, Varun Bhalerao, et al. (2020) *GRB 201009A: AstroSat CZTI detection*, GCN Circular No. 28589.
37. **Soumya Gupta, Vidushi Sharma, Ajay M. Vibhute, Dipankar Bhattacharya**, Varun Bhalerao, et al. (2020) *GRB 201013A: AstroSat CZTI detection*, GCN Circular No. 28620.
38. **Soumya Gupta, Vidushi Sharma, Ajay M. Vibhute, Dipankar Bhattacharya**, Varun Bhalerao, et al. (2020) *GRB 201016A: AstroSat CZTI detection*, GCN Circular No. 28651.
39. **Soumya Gupta, Vidushi Sharma, Ajay M. Vibhute, Dipankar Bhattacharya**, Varun Bhalerao, et al. (2020) *GRB 201019B: AstroSat CZTI detection*, GCN Circular No. 28695.
40. **Soumya Gupta, Vidushi Sharma, Ajay M. Vibhute, Dipankar Bhattacharya**, Varun Bhalerao, et al. (2020) *GRB 201104A: AstroSat CZTI detection*, GCN Circular No. 28873.
41. **Soumya Gupta, Vidushi Sharma, Ajay M. Vibhute, Dipankar Bhattacharya**, Varun Bhalerao, et al. (2020) *GRB 201114A: AstroSat CZTI detection*, GCN Circular No. 28885.
42. **Soumya Gupta, Pallavi V. Sawant, Vidushi Sharma, Ajay M. Vibhute, Dipankar Bhattacharya**, et al. 2020, *GRB 201207A: AstroSat CZTI detection*, GCN Circular No. 29000.
43. **Pallavi V. Sawant, ..., Ajay M. Vibhute, Soumya Gupta**, Varun Bhalerao, **Dipankar Bhattacharya**, et al. (2021) *GRB 210324C: AstroSat CZTI detection*, GCN Circular No. 29734.
44. **Pallavi V. Sawant, ..., Ajay M. Vibhute, Soumya Gupta**, Varun Bhalerao, **Dipankar Bhattacharya**, et al. (2021) *GRB 210324A: AstroSat CZTI detection*, GCN Circular No. 29735.
45. **Pallavi V. Sawant, ..., Ajay M. Vibhute, Soumya Gupta**, Varun Bhalerao, **Dipankar Bhattacharya**, et al. (2021) *GRB 210328A: AstroSat CZTI detection*, GCN Circular No. 29746.
46. **Pallavi V. Sawant, ..., Ajay M. Vibhute, Soumya Gupta**, Varun Bhalerao, **Dipankar Bhattacharya**, et al. (2021) *GRB 210330A: AstroSat CZTI detection*, GCN Circular No. 29749.
47. **Drishika Nadella, A. Marathe, ..., Ajay M. Vibhute, Soumya Gupta, Dipankar Bhattacharya**, et al. (2020) *GRB 201208A: AstroSat CZTI detection*, GCN Circular No. 29001.



48. Drishika Nadella, ..., **Ajay M. Vibhute, Soumya Gupta, Pallavi V. Sawant, Dipankar Bhattacharya**, et al. (2020) *GRB 201209A: AstroSat CZTI detection*, GCN Circular No. 29011.
49. Drishika Nadella, ..., **Ajay M. Vibhute, Soumya Gupta, Pallavi V. Sawant, Dipankar Bhattacharya**, et al. (2020) *GRB 201216C: AstroSat CZTI detection*, GCN Circular No. 29074.
50. Drishika Nadella, ..., **Ajay M. Vibhute, Soumya Gupta, Pallavi V. Sawant, Dipankar Bhattacharya**, et al. (2021) *GRB 210104A: AstroSat CZTI detection*, GCN Circular No. 29299.
51. Drishika Nadella, ..., **Ajay M. Vibhute, Soumya Gupta, Pallavi V. Sawant, Dipankar Bhattacharya**, et al. (2021) *GRB 210116A: AstroSat CZTI detection*, GCN Circular No. 29342.
52. Drishika Nadella, ..., **Ajay M. Vibhute, Soumya Gupta, Pallavi V. Sawant, Dipankar Bhattacharya**, et al. (2021) *GRB 210123A: AstroSat CZTI detection*, GCN Circular No. 29366.
53. Drishika Nadella, ..., **Ajay M. Vibhute, Soumya Gupta, Pallavi V. Sawant, Dipankar Bhattacharya**, et al. (2021) *GRB 210124B: AstroSat CZTI detection*, GCN Circular No. 29367.
54. Drishika Nadella, ..., **Ajay M. Vibhute, Soumya Gupta, Pallavi V. Sawant, Dipankar Bhattacharya**, et al. (2021) *GRB 210126A: AstroSat CZTI detection*, GCN Circular No. 29368.
55. Gaurav Waratkar, ..., **Ajay M. Vibhute, Soumya Gupta, Pallavi V. Sawant, Dipankar Bhattacharya**, et al. (2021) *GRB 210204A: AstroSat CZTI Detection*, GCN Circular No. 29410.
56. Gaurav Waratkar, ..., **Ajay M. Vibhute, Soumya Gupta, Pallavi V. Sawant, Dipankar Bhattacharya**, et al. (2021) *GRB 210207B: AstroSat CZTI detection*, GCN Circular No. 29437.

d) POPULAR ARTICLES

Pratik Dabhade and Mousumi Mahato

- *Giant radio galaxies: The cosmic behemoths*, Nature Astronomy Community
[<https://astronomycommunity.nature.com/posts/giant-radio-galaxies-the-cosmic-behemoths>].

Jayant V. Narlikar

- *Star scientist*, Frontline, May 22, 2020.
- *Tribute to Govind Swarup*, Times of India, September 9, 2020.
- *Rashtriya ekata, vidnyan aur hindi bhasha* (in Hindi) (*National integration, science and Hindi language*), Vyom, Issue 3, September 2020.
- *Govind Swarup* (in Hindi), Vyom, Issue 17, September 2020.
- *Pruthvi palikadil sajeev srushti?* (in Marathi) (*Extraterrestrial life?*), Akshargandh, Diwali Issue 10, 2020.
- *Pruthvivar yenaare sukshmajeev?*, (*Microbe visitors to the Earth?*), Bhavatal, Diwali Issue 30, 2020.



(a) IUCAA–NCRA Graduate School

Debarati Chatterjee

Quantum and Statistical Mechanics II (14 lectures) (December 2020 – February 2021).

Gulab C. Dewangan

Astronomical Techniques I (14 lectures) (March – April 2021).

Ranjeev Misra

Electrodynamics and Radiative Processes II (14 lectures) (December 2020 – February 2021).

Sanjit Mitra

Methods of Mathematical Physics II (14 lectures) (December 2020 – February 2021).

Dipanjan Mukherjee

Electrodynamics and Radiative Processes I (15 lectures) (October – December 2020).

Somak Raychaudhury

Introduction to Astronomy and Astrophysics I (21 lectures) (October – December 2020).

Research Methods and Statistical Techniques (7 lectures) (March – April 2021).

Kanak Saha

Galaxies: Structure, Dynamics and Evolution (21 lectures) (March – April 2021).

Nishant K. Singh

Methods of Mathematical Physics I (21 lectures), and *Numerical Errors* (1 lecture) (October – December 2020).

Raghunathan Srianand

Interstellar Medium (14 lectures) (March – May 2021).

Durgesh Tripathi

Research Methods and Statistical Techniques (7 lectures) (March – April 2021).



(b) SAVITRIBAI PHULE PUNE UNIVERSITY MSc LECTURES

(Departments of Physics, and Department of Space Science)

Neeraj Gupta

Radio Astronomy (Theory 4 lectures), and related experiments.

Ranjan Gupta

Astronomy and Astrophysics Laboratory Course (Theory 10 lectures), and related to *Observational Astronomy* (10 lectures and Night Experiments).

Surhud More

Astronomy and Astrophysics - II, Cosmology (24 lectures) (January – April 2021).

Dhurba J. Saikia

Astronomy and Astrophysics – I, Introductory Astronomy and Astrophysics (40 lectures) (August – December 2020).

Kandaswamy Subramanian

Astronomy and Astrophysics - II, General Relativity (17 lectures) (January – April 2021).

(c) SUPERVISION OF PhD THESES

(Degrees Awarded)

Dipankar Bhattacharya

Title: *Gamma Ray Bursts with AstroSat*.

Student: Vidushi Sharma (IUCAA)

Title: *Indirect Imaging in Astronomy*.

Student: Ajay M. Vibhute (Savitribai Phule Pune University)

Somak Raychaudhury

Title: *The Evolution of Galaxies on the Cosmic Web*.

Student: Ruchika Seth (IUCAA)

Tarun Souradeep

Title: *Study of CMB Spectral Distortions*.

Student: Debajyoti Sarkar (IUCAA)



(d) SUPERVISION OF PhD THESES

(Ongoing)

Dipankar Bhattacharya

Title: *Accretion-Induced Evolution of Neutron Star Magnetic Field.*

Student: Suman Bala (IUCAA)

and **Ranjeev Misra** (Co-supervision)

Title: *Spectro-Timing Study of Accretion Disks.*

Student: Yash Bhargava (IUCAA)

and **Dipanjan Mukherjee** (Co-supervision)

Title: *An Investigation of Polarised Emission from Accreting Binary X-Ray Pulsars.*

Student: Parisee Shirke (IUCAA)

Sukanta Bose

Title: *Constraining the Equation of State of Neutron Stars with Gravitational Wave Observations.*

Student: Bhaskar Biswas (IUCAA)

Title: *Improved Methods for Discriminating Gravitational Wave Signals of Compact Binary Coalescences from Noise Transients.*

Student: Sunil Choudhary (IUCAA)

Title: *Spacetime Mapping.*

Student: Sayak G. Datta (IUCAA)

Title: *Numerical Study of Wave Propagation in General Relativity.*

Student: Shalabh Gautam (IUCAA)

Title: *Measuring Cosmological Parameters with Gravitational-wave Observations.*

Student: Tathagata Ghosh

and **Anupreeta More** (Co-Supervision)

Title: *Using Gravitational Waves from Compact Binary Coalescences to Probe Gravitational Lensing (Strong and Micro) and the Magnetic Penrose Process.*

Student: Anuj Mishra

Title: *Characterizing the Properties and Constitution of Compact Objects in Gravitational Wave Binaries.*

Student: Samanwaya Mukherjee (IUCAA)

Title: *The Physics and Astrophysics of Binary Black Hole Mergers and their Gravitational Radiation.*

Student: Vaishak Prasad (IUCAA)



Debarati Chatterjee

Title: *Transport Properties in Neutron Stars and their Role in Gravitational Wave Emission.*

Student: Suprovo Ghosh (IUCAA)

Title: *Study of the Role of Neutron Star Composition on Gravitational Wave Emission.*

Student: Bikram K. Pradhan (IUCAA)

Subhadeep De (Co-Supervision)

Title: *Instrumentation of Optical Clock and its Signal Distribution.*

Student: Harish Rathor (AcSIR, CSIR – NPL, New Delhi)

Title: *Development of the Optical Set-up for Ytterbium Ion Optical Frequency Standards.*

Student: Lakhi Sharma (AcSIR, CSIR – NPL, New Delhi)

Title: *Modulation and Stabilization of Optical Frequencies for Lase Cooling of 171 Yb Ions.*

Student: Shubham Utreja (AcSIR, CSIR – NPL, New Delhi).

Title: *Automation, Signal Processing and Precision Frequency Transfer.*

Student: Neelam Yadav (AcSIR, CSIR – NPL, New Delhi)

Gulab C. Dewangan

Title: *Active Galactic Nuclei and Bright UV Sources in the AstroSat/UVIT Fields.*

Student: Piyali Ganguly (IUCAA)

Title: *AstroSat View of Accretion Discs in Active Galactic Nuclei.*

Student: Shrabani Kumar (IUCAA)

Title: *Accretion Disk – Corona Interplay in Active Galactic Nuclei.*

Student: Kavita Kumari (IUCAA)

Title: *Soft X-ray Excess and Accretion Disk/Corona Emission from Active Galactic Nuclei.*

Student: Prakash Tripathi (IUCAA)

Neeraj Gupta

Title: *An Unbiased View of Cold Atomic Gas Associated with Radio-Loud AGNs.*

Student: Partha P. Deka (IUCAA)

Sanjit Mitra

Title: *Methods and Scientific Potentials of Stochastic Gravitational Wave Background Analysis.*

Student: Deepali Agarwal (IUCAA)



Title: *Algorithms for Gravitational Wave Data Analysis and Detector Controls Based on Modern Techniques.*

Student: Shreejit Jadhav (IUCAA)

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

Student: Kanchan Soni (IUCAA)

Surhud More

Title: *Gravitational Lensing Probes of Dark Matter.*

Student: Priyanka Gawade (IUCAA)

Title: *Gravitational Lensing in Galaxy Clusters.*

Student: Amit Kumar (IUCAA)

Title: *Probing Cosmology with Large Scale Structure Correlations*

Student: Divya Rana (IUCAA)

and **Anupreeta More** (Co-supervision)

Title: *Gravitational Lensing: Galaxy Dark Matter Connection and Cosmology.*

Student: Navin Chaurasiya (IUCAA)

Dipanjan Mukherjee

Title: *Modelling the Impact of AGN Driven Outflows on the Star Formation Activity in Galaxies.*

Student: Anksuh Mandal (IUCAA)

Title: *Simulating Effects of AGN Driven Outflows on Galactic Scales and Predicting their Observable Signatures.*

Student: M. Meenakshi (IUCAA)

Aseem Paranjape

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

Student: Bhaskar Arya (IUCAA)

Title: *Interplay of Galaxy Formation and the Evolution of Dark Matter Haloes in the Cosmic Web.*

Student: V. Premvijay (IUCAA)

Title: *Halo Dynamics and Kinematics: Applications to Large Scale Structure and Cosmology.*

Student: Sujatha Ramakrishnan (IUCAA)

A. N. Ramaprakash

Title: *Alternative Techniques for Adaptive Optics for Future Large Telescopes.*

Student: Sorabh Chhabra (IUCAA)



Title: *Design and Development of Wide-Field Polarimeter (WALOP) for Skinakas Observatory for PASIPHAE Survey* (Co-supervision).

Student: John Kypriotakis (University of Crete, Greece)

Title: *Design and Development of Wide Field Optical Polarimeters (WALOP) for Dust Cloud Tomography.*

Student: Siddharth Maharana (IUCAA)

Title: *Probing Magnetic Fields using Stellar Polarization* (Co-supervision).

Student: Shrish (NISER, Bhubaneswar)

Title: *Development of UV Detectors for Solar Astronomy* (Co-supervision).

Student: Manoj Varma (IIA, Bengaluru)

Varun Sahni

Title: *Dark Matter, Dark Energy and the Early Universe.*

Student: Swagat S. Mishra (IUCAA)

Nishant K. Singh

Title: *Aspects of Turbulent Convection: Implications for Solar Differential Rotation and Small Scale Dynamos.*

Student: Kishore Gopalakrishnan (IUCAA)

Title: *Dynamo Action in Rotating and Shearing Flows* (Co-supervision).

Student: Naveen Jingade (IISc, Bengaluru)

Title: *Towards Constraining the Solar Dynamo with Observational Studies of the Sun's Magnetic Field* (Co-supervision).

Student: Ameya Prabhu (Max Planck Institute for Solar System Research, Germany)

Tarun Souradeep

Title: *Physics beyond Statistical Isotropy at Late Universe.*

Student: Debabrata Adak (IUCAA)

Raghunathan Srianand

Title: *Probing the Ultra-Fast Outflows in BAL Quasars using Multi-Epoch Spectroscopy.*

Student: P. Aromal (IUCAA)

Title: *Probing the Nature, Environment and Evolution of Ultra Strong Mg II Absorption Systems.*

Student: Labanya K. Guha (IUCAA)

Title: *Probing the Physical State of the Intergalactic Medium and Quasar Environment* (Co-supervision).

Student: Priyanka Jalan (ARIES, Nainital)



Title: *Probing the Astrophysical and Cosmological Aspects of Intergalactic Medium using Quasar Spectra.*

Student: Soumak Maitra (IUCAA)

Title: *Exploring the Metals in the Intergalactic Medium.*

Student: Sukanya Mallik (IUCAA)

Title: *Probing the Circumgalactic Medium with Quasar Absorption Lines (Co-supervision).*

Student: Abhisek Mohapatra (NIT, Rourkela)

Title: *Probing Environment of High Redshift Quasars using Diffuse Lyman- α Emission.*

Student: Gitika P. Shukla (IUCAA)

Durgesh Tripathi

Title: *Energetics of the Solar Atmosphere.*

Student: Abhishek Rajhans (IUCAA)

Title: *Dynamics of the Lower Solar Atmosphere.*

Student: Soumya Roy (IUCAA)

Title: *Heating and Dynamics of the Solar Atmosphere.*

Student: Vishal Upendran (IUCAA)

(e) SUPERVISION OF PROJECTS

Debarati Chatterjee

Radhika Agarwal (IIT, Gandhinagar) *Study of Correlations between Nuclear and Astrophysical Observables.*

Sukrit Jaiswal (IISER, Pune) *Constraining Dense Matter Physics using f -mode Oscillations in Neutron Stars.*

Ayush Sahu (CBS, Pt. Ravishankar Shukla University, Raipur) *Role of Prior in Bayesian Analysis of Neutron Star Equation of State.*

Sorabh Chhabra

Kriti Baweja (Delhi University) *Developing Diffraction Limited Imaging Systems.*

L.S. Namitha (Hyderabad University) *Simulating Atmospheric Phase Screen.*

Ranjit A. Pal (NISER, Kolkata) *Obtaining Diffraction Limited Object from Speckle Image Technique.*



Gulab C. Dewangan

Partha P. Deka (IUCAA) *Searching for Dual Nuclei in Galaxies using AstroSat UVIT.*

Kavita Kumari (IUCAA) *Characterizing AGN Variability with Fractional Variability Amplitude Spectrum.*

Sanjeev V. Dhurandhar

Prasanna Joshi (IISER, Pune) *Optimal Chi-Square Veto for Sine-Gaussian Glitches.*

Adhishree Lahiri, and Abhishek Kulkarni (Fergusson College, Pune) *Special and General Relativity and its Applications.*

Pranjal Upadhyaya (IISER, Pune) *Improving the Radiometric Search for the Stochastic Gravitational Wave Background using a Natural Set of Basis Functions.*

Suresh Doravari

Richal Abhang (LIGO – India) *Monolithic Folded-Pendulum Seismometer.*

Ninad Bhagwat (LIGO – India) *Design and Fabrication of a Seismic Isolation Platform using Roberts Linkage.*

Prachit Kamble (LIGO – India) *Design of a Vertical Seismic Isolator based on Geometric Anti-Spring.*

Aditya Vidhate (LIGO – India) *Predicting Sensor and Actuator Signals in GW Detectors from the Dark Port Video Stream using Neural Networks.*

Sanjit Mitra

Ananya Bandopadhyay (IISER, Pune) *Joint Estimation of Binary Population Parameters from the Observation of Gravitational Waves from Individual Mergers and the Stochastic Background.*

Anupreeta More

Shreeja Ghugal (IISER, Pune) *A Tool to Identify Quadruply Lensed Quasar Images.*

Divyam Kalra (Punjab Engineering College, Chandigarh) *Neural Network Based Search for Doubly Lensed Quasars.*

Chatrik S. Mangat (BITS – Pilani, Hyderabad) *Cosmological Constraints using a Double Source Plane Lens System.*

Rishabh Wanjari (IISER, Pune) *Unsupervised ML on BicoH Data.*



Surhud More

Souradip Bhattacharya (Presidency University, Kolkata) *The Signatures of Self-Interacting Dark Matter and Subhalo Disruption on Cluster Substructure.*

Manav Chordia (Pune Institute of Computer Technology) *Machine Learning to Improve Difference Imaging in Astronomy.*

Shefali Negi (Punjabi University, Patiala) *Difference Imaging Applications in Astrophysics.*

Suraj Patil (Savitribai Phule Pune University) *Searching for Binary Systems with Invisible Counterparts in GAIA Data.*

Arindam Sharma (IISER, Pune) *Cosmology from Galaxy Clusters.*

Dipanjan Mukherjee

Ameya Nagdeo (CEBS, University of Bombay, Mumbai) *Semi-Relativistic Magneto-hydrodynamic Solver.*

Aseem Paranjape

Payaswinee Dhoke (M. P. Deo Memorial College, Nagpur) *Environmental Effects on Mass Accretion in Warm Dark Matter Cosmologies.*

A.N. Ramaprakash

Kadambari Bhujbal (VIT, Vellore) *Automation of WALOP CCD and IDSAC Electronics Characterization and Analysis.*

Kanak Saha

Shashwat Sharma (St. Xavier's College, Mumbai) *Orbital Studies in a Milky Way like Potential.*

Dhurba J. Saikia

Rushikesh N. Bhutkar (Savitribai Phule Pune University) *Compact Steep Spectrum Radio Sources and Unification Scheme (Co-Supervised by Yogesh Chandola).*

Rahul Musale (Savitribai Phule Pune University) *Compact Steep Spectrum Radio Sources and Symmetry Parameters (Co-Supervised by Yogesh Chandola).*

Nishant K. Singh

Kishore Gopalakrishnan (IUCAA) *Estimation of the Extent of Convective Penetration into Sub-adiabatic Layers.*



Raghunathan Srianand

Sukanya Mallik (IUCAA) *Exploring Metals in IGM.*

Kandaswamy Subramanian

Ankita Gurav (Savitribai Phule Pune University) *Galaxy Formation.*

(f) SEMINARS, COLLOQUIA, AND LECTURES (Online)

Dipankar Bhattacharya

AstroSat/CZT Imager, CalTech, USA, August 17, 2020.

Polarised High Energy Emission from Astrophysical Sources, RRI, Bengaluru, August 25, 2020.

Matter at Extreme Density - What do Neutron Stars Tell us?, Introductory Seminar on Astrophysics and Cosmology, ICARD, North Bengal University, Siliguri, September 16, 2020.

The Magnetic Fields of Neutron Stars, IUCAA, November 5, 2020.

Studying Polarised High Energy Emission with AstroSat CZT Imager, India – China Workshop on High Energy Astrophysics, November 16, 2020.

Spin-Powered Millisecond Pulsars: Pathways to Formation, 43rd COSPAR Scientific Assembly, Sydney, Australia, January 29, 2021.

Pulsars, Winter School in Observational Astronomy, IIT, Indore, February 9, 2021.

AstroSat – The First Five Years, IIT, Guwahati, March 16, 2021.

Debarati Chatterjee

Probing Neutron Stars with Gravitational Waves, LIGO – India GW@Home, IUCAA, Lecture Series, May 8, 2020.

Constraining Dense Matter Physics using F-mode Oscillations in Neutron Stars, IUCAA, July 30, 2020.

Using Neutron Stars Oscillations to Constrain Dense Matter Physics, Compact Stars and QCD, ICTS, Bengaluru, August 19, 2020.

Pulsars as Probes of Extreme Matter, IIT, Kharagpur, September 15, 2020.

Neutron Star Oscillations as Probes of Dense Nuclear Matter, Nuclear Theory Groups of University of Houston, and University of Illinois, Urbana Champaign, October 9, 2020.

Pulsars, Radio Astronomy Winter School, IUCAA and NCRA-TIFR, Pune, January 5, 2021.

Gravitational Waves as a Tool to Probe Extreme Physics, IIT, Gandhinagar, March 14, 2021.



Pratik Dabhade

Project SAGAN- Search and Analysis of Giant Radio Galaxies with Associated Nuclei, Astronomical Institute of the Czech Academy of Sciences, Prague, September 18, 2020.

Giant Radio Galaxies and their Properties, Observatoire de Paris, November 25, 2020.

Subhadeep De

Atomic Clock and their Applications, GNDU, Amritsar, May 18, 2020.

Probing Fundamental Science using Optical Atomic Clock, IUCAA, July 2, 2020.

Accurate Measurement of Time for Synchronizing the Detectors, GW@ Home, EPO, LIGO – India, IUCAA, July 20, 2020.

Optical Atomic Clock and Quantum Metrology, Recent Trends and Developments in Secure Quantum Communication as Well as Quantum Sensing and Metrology, RRI, Bengaluru, August 17 – 18, 2020.

Atomic Clocks: That Slips 1s over the Age of the Universe, Symbiosis International School, Pune, September 18, 2020.

Optical Atomic Clocks to Probe Fundamental Science, 39th Meeting of the ASI, February 18 – 23, 2021.

Sundial to an Atomic Clock for Accurate Timekeeping and Fundamental Science, National Science Day, IUCAA, February 28, 2021.

Gulab C. Dewangan

X-ray/UV Emission from Active Galactic Nuclei, International Symposium on Advanced Research in Physics, Bangalore University, Bengaluru, July 27 – 31, 2020.

Active Galactic Nuclei, Introductory Seminar on Astrophysics and Cosmology, ICARD, Department of Physics, North Bengal University, September 16, 2020; and Fifth Arab School for Astrophysics, National Research Institute of Astronomy and Geophysics (NRIAG), Cairo, October 16 – 23, 2020.

AstroSat Calibration Status/Issues, International Astrophysical Consortium for High Energy Calibration, MIT, Cambridge, USA, November 23 – 24, 2020.

Multi-wavelength Spectroscopy with AstroSat, Five Years of UVIT Meeting, IIA, Bengaluru, December 2, 2020.

Multi-wavelength Study of AGNs with AstroSat, AstroSat Five Years Meeting, ISRO, Bengaluru, January 19 – 21, 2021.

(i) *Multi-wavelength Observations of Compact Objects with AstroSat*, and (ii) *UV/X-ray Connection in AGN*, 43rd COSPAR Scientific Assembly, Sydney, Australia, January 28 – February 4, 2021.



Probing Accretion Disks of Compact Objects with UVIT Spectroscopy, Workshop on Ultraviolet Space Astronomy: UVIT and Beyond (WS2), 39th Meeting of the ASI, February 18–23, 2021.

Sanjeev V. Dhurandhar

Extracting Gravitational Wave Signals from Detector Noise, IUCAA, April 17, 2020.

Gravitational Waves and Overview, Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, May 20, 2020.

Gravitational Waves: From Discovery to Astronomy, Department of Physics, Goa University, October 3, 2020.

Black Holes in Diapers, Special Session in Honour of C. V. Vishveshwara, 31st Meeting of the IAGRG, IIT, Gandhinagar, December 19–20, 2020.

Relativity Special and General, Black Holes, and Gravitational Waves, UG and PG Students, EPO, LIGO – India, IUCAA, January 25, 2021.

Suresh Doravari

Introduction to Length Sensing in Advanced LIGO, Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, June 12, 2020.

A Tryst with Interferometry, International Association of Physics Students, Delhi, October 11, 2020.

Future GW Detectors and Opportunities with LIGO – India Gravitational Wave Science Communicators' Programme, IUCAA, January 31, 2021.

Neeraj Gupta

Large Survey with SALT: Radio Bright Quasars for the MeerKAT Absorption Line Survey, Indo – South Africa Bilateral Science Workshop, IUCAA, January 12, 2021.

The MeerKAT Absorption Line Survey: Evolution of Cold Gas in Galaxies, 39th Meeting of the ASI, February 20, 2021; and SKA Science Meeting (A precursor view of the SKA sky), Manchester, UK, March 16, 2021.

Ranjan Gupta

India's Mega Projects in Astronomy, Department of Physics, Digboi College, July 24, 2020.

Shivaraj Kandhasamy

Update on LVK Stochastic Gravitational Wave Group Activities, LIGO – VIRGO – KAGRA Collaboration Meeting, University of Glasgow, UK, September 16, 2020.



Ranjeev Misra

Black Holes in the Universe, Fifth Arab School in Astronomy, Cairo, October 2020.

Identifying the QPO Frequencies of GRS 1915+105 as General Relativistic Dynamic Ones, Relativistic Astrophysics, Theory and Observational Perspectives, Warsaw, Poland, March 2021.

Sanjit Mitra

(i) *Surfing Gravitational Waves*, April 1, 2020; and (ii) *To Search for Unknown Sources of Gravitational Waves*, April 22, 2020, IUCAA, GW@Home.

PyStoch and Spherical Harmonic Search, Stochastic Group F2F, LIGO – Virgo – KAGRA Collaboration Meeting, Glasgow, September 15, 2020.

Updates on the All Sky All Frequency, Stochastic Group F2F, LIGO – Virgo – KAGRA Collaboration Meeting, Milwaukee, March 16, 2021.

Anupreeta More

Strong Gravitational Lensing, Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, May 28, 2020.

Gravitationally Lensed SNe, ILMT Workshop, ARIES, Nainital, June 20, 2020.

Searches of Lensed Transients and Variables, Time Domain Cosmology with Strong Lensing Workshop, Kavli IPMU, University of Tokyo, January 25, 2021.

Surhud More

Astrophysics Experimental Physics and Cosmology, Kavli IPMU, University of Tokyo, August 27, 2020.

Pheno, IISc, Bengaluru, October 7, 2020.

Sowgat Muzahid

MUSEQuBES and MEGAFLOW: MUSE Surveys on the Circumgalactic Medium, IUCAA, January 2021.

Jayant V. Narlikar

Bhaskara and Leelavati, IIIT, Kurnool, November 21, 2020.

Searches for Extraterrestrial Micro-Life, Krishnaji Memorial Lecture, NASI, IISER, Pune, February 25, 2021.



T. Padmanabhan

The Fluid we Call Spacetime, Mysteries of the Universe, IIT, Roorkee, March 20, 2021.

Aseem Paranjape

Cosmic Tides and Structure Formation, ICTP – EAIFR, Bengaluru, September 25, 2020.

A.N. Ramaprakash

Magnetic Fields Tomography of Milky Way, Southern Regional Astronomy Meet, WMO College, Muttill, Wayanad; and Newman College, Thodupuzha, July 9, 2020.

Next Generation Challenges in Astrotechnology, Rajagiri School of Engineering and Technology, Kakkanad, August 12, 2020.

Seeing the Stars, Winter School on Observational Astronomy, Ujjain Planetarium, Dongla, February 4, 2021.

WALOP/PASIPHAЕ, Indo-French CEFIPRA Astronomy Meeting, IIA, Bengaluru, March 25, 2021.

Kanak Saha

एस्ट्रोसैट द्वारा चरम-यूवी प्रकाश में एक दूर की आकाशगंगा की खोज , Hindi Divas, IUCAA, September 14, 2020.

AstroSat Detects a $z = 1.42$ Galaxy Emitting Lyman Continuum Photons, IUCAA, September 17, 2020; AstroSat Five Years Special Meeting, ISRO, Bengaluru, September 28, 2020; and Five Years of AstroSat Meeting, ISRO, Bengaluru, February 12, 2021.

AstroSat Detection of Extreme-UV Light from a Distant Galaxy, Department of Physics, Newman College, Thodupuzha, September 26, 2020; Department of Physics, Gauhati University, Guwahati, October 17, 2020; and North East Meet of Astronomers, IIT, Guwahati, November 10, 2020.

AstroSat Detection of a $z = 1.42$ Galaxy Emitting Extreme-UV Photons, Department of Physics, IISc, Bengaluru, October 9, 2020.

The Discovery of a Far Away Galaxy using the Indian Space Observatory – AstroSat, ICFAI University, Tripura, October 14, 2020.

UV Properties of Star Forming Galaxies, Ultraviolet Workshop, Mahatma Gandhi University, Kottayam, December 7, 2020.

Galaxy Evolution: Simulation, Observations and Data Analysis, India – South Africa Bilateral Science Workshop, IUCAA, January 12, 2021.

AstroSat Detection of Lyman Continuum Photons from a Distant Galaxy, TIFR, Mumbai, December 8, 2020; and 39th Meeting of the ASI, February 23, 2021.



Lopsidedness in Minor Mergers, Double-Peak Emission Line Galaxies, Observatoire de Paris, February 24, 2021.

AstroSat Detection of a Distant Galaxy in Extreme-UV Light, National Seminar on Recent Advances in Astrophysics and Cosmology, North Bengal University, Siliguri, March 24, 2021.

Dhurba J. Saikia

The Radio Universe, Radio Astronomy Winter School, IUCAA, and NCRA – TIFR, Pune, December 28, 2020.

Extracting Energy from Gravity, Frontiers in Physics – XIV, Fergusson College, Pune, March 24, 2021.

Vaibhav N. Savant

LIGO – India: Education and Public Outreach Efforts, Global Hands-on Universe Conference, IUCAA, August 27, 2020.

Nishant K. Singh

Magnetic Fields in Universe: Galaxies to Helioseismology – Current Trends in Research and Career Scope, Current Trends in Physics, Diamond Jubilee Year Celebration, S.D. College, Alappuzha, November 21, 2020.

Potential Role of Solar f -mode in Space Weather Forecasting, SUIT Science Meeting, IUCAA, January 11 – 13, 2021.

(i) *Computational Astrophysics: An Emerging Avenue for Indian Astronomy Community*, February 18, 2021; and (ii) *Sun and Solar System*, February 21, 2021; 39th Meeting of the ASI.

Self-consistent Formation of Sunspot Like Magnetic Flux Concentrations, Conference on Advances in Observations and Modelling of Solar Magnetism and Variability, IIA, Bengaluru, March 1 – 4, 2021.

Kandaswamy Subramanian

Challenges: The Origin of Cosmic Magnetism, North East Meet of Astronomers, IIT, Guwahati, November 10 – 13, 2020.

Manasadevi P. Thirugnanasambandam

Folded Interferometers for Gravitational Waves Detection, Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, June 12, 2020.

Durgesh Tripathi

Coupling and Dynamics of Waves in the Solar Atmosphere, SP²RC, Department of Physics, University of Sheffield, UK, May 8, 2020.



The Aditya-L1 Mission of Indian Space Research Organisation, SP²RC, Department of Physics, University of Sheffield, UK, July 3, 2020; and Department of Astronomy, New Mexico State University, USA, February 12, 2021.

Geo-effectiveness of Solar Storms, NASA-SETI Frontier Development Lab, SETI Institute, Mountain View, California, and NASA Ames Research Centre, California. August 14, 2020.

Hydrodynamics of Hi-C Brightenings, European Solar Physics Seminar, Roseland Centre for Solar Physics, Norway, September 24, 2020.

ISRO's First Solar Observatory in Space: The Aditya-L1 Mission, American Geophysical Union, USA December 1 – 17, 2020.

Solar Prominences and Flares: What New Aditya – L1 Mission Can Tell us, 2nd Aditya – L1 Science Meeting, Bengaluru, December 17, 2020.

(i) *Sun-climate Studies with the Solar Ultraviolet Imaging Telescope on board Aditya-L1*, and (ii) *Heliophysics Public Outreach in India*, 43rd COSPAR Scientific Assembly, Sydney, Australia, January 28 – February 4, 2021.

Observing the Sun, Winter School in Observational Astronomy, Varahamihir Astronomical Observatory, Dongla; and Ujjain Planetarium, February 1 – 12, 2021.

(i) *A Unified Scenario for the Heating of the Corona in Quiet Sun, Coronal Holes and Formation of Solar Wind*, and (ii) *Quiet Sun Coronal Heating by Nanoflares*, 39th Meeting of the ASI, February 18 – 23, 2021.

Multi-height Observations of Waves in the Solar Atmosphere using SUIT on board Aditya – L1, ASI Workshop on Multi-payload and Multi-observatory Science with Aditya – L1, Bengaluru, February 19, 2021.

The Aditya – L1 Mission, National Science Day, VIT, Bhopal, February 28, 2021.

The Solar Ultraviolet Imaging Telescope on board Aditya – L1, Advances in Observations and Modelling of Solar Magnetism and Variability, IIA, Bengaluru, March 1 – 4, 2021.

(g) LECTURE COURSES (Online)

Joydeep Bagchi

Supermassive Black Holes and Relativistic Jets (2 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, June 10, 11, 2020.

Dipankar Bhattacharya

Computational Methods in Astronomy (4 lectures), Topical Course, IUCAA, April – May 2020.



Radiative Processes (4 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, May 11, 12, 13, 14, 2020.

Stellar Theory (3 lectures), Meeting on Compact Stars and QCD, ICTS, Bengaluru, August 17 – 19, 2020.

Radiative Processes in Astrophysics (2 lectures), Radio Astronomy Winter School, IUCAA, and NCRA – TIFR, Pune, December 31 – January 1, 2021.

An Advanced Course on Pulsar Astrophysics (20 recorded lectures and 10 live contact hours), Astronomy Centre for Educators, IUCAA, February 1 – April 5, 2021.

Sukanta Bose

General Relativity (3 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, May 18, 19, 2020.

Debarati Chatterjee

Compact Astrophysics Objects (2 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, June 2, 3, 2020.

Subhadeep De

Atomic Clocks and Fundamental Physics (2 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, June 4, 5, 2020.

Avinash Deshpande

Radio Astronomy Basics, and SWAN/Radio Pulsars (2 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, June 5, 8, 2020.

Gulab C. Dewangan

X-ray Astronomy and Active Galactic Nuclei (2 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, June 1, 3, 2020.

Neeraj Gupta

Radio Astronomy: Current and Next Generation Telescopes (3 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, June 1, 3, 5, 2020.

Ranjan Gupta

Photometry and Spectroscopy (2 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, May 14, 15, 2020.

Introduction to Spectroscopy and Instrumentation (2 lectures), 6th Indo – French Astronomy School on Spectroscopy – Treasures in Voxels' (IFAS6), Lyon, France, July 9 – 17, 2020.



Ajit K. Kembhavi

Big Data and Machine Learning + Precision Measurements in Astronomy (3 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, June 9, 10, 11, 2020.

Ranjeev Misra

Observational Evidence for Black Holes (2 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, June 1, 2, 2020.

Sanjit Mitra

Gravitational Waves and LIGO (3 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, May 21, 22, and June 4, 2020.

Dipanjan Mukherjee

Numerical Modelling of Astrophysical Flows (2 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, May 29, 2020.

Surhud More

Introduction to Gravitational Lensing/Weak Lensing (2 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, May 27, 29, 2020.

Aseem Paranjape

Cosmology (4 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, May 20, 21, 22, 2020.

Generating Mock Catalogues (3 lectures and hands-on exercises), 39th Meeting of the ASI, February 19, 2021.

A.N. Ramaprakash

Astronomical Instrumentation and Thirty Metre Telescope (2 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, June 8, 9, 2020.

Somak Raychaudhury

(i) *Introduction to Astronomy and Astrophysics* (4 lectures), May 11, 12, 13, 14, 2020; and (ii) *Galaxy Clusters* (2 lectures), June 2, 4, 2020, Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA.



Kanak Saha

Computational Methods in Astronomy: Discrete Particle Dynamics and Direct Imaging Method (6 lectures), IUCAA, April 20 – 27, and 30, 2020.

Galaxies and Galactic Dynamics (3 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, May 26, 27, 28, 2020.

Astrophysics and Astronomical Measurements (12 lectures), MSc Class, Cooch Behar Panchanan Barma University, June – July 2020.

Introduction to UV Spectroscopy (2 lectures), 6th Indo – French Astronomy School on Spectroscopy – Treasures in Voxels' (IFAS6), Lyon, France, July 9 – 17, 2020.

Astrophysics (24 lectures), MSc Class, St. Xavier's College, Mumbai, September – November 2020.

Varun Sahni

Dark Matter and Dark Energy (2 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, June 8, 9, 2020.

Dhurba J. Saikia

Active Galaxies (2 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, June 10, 11, 2020.

(i) *Multi-messenger Astronomy* (3 lectures), January 27 – 30, 2021; (ii) *Galaxies: An Overview* (2 lectures), March 4 – 6, 2021; and (iii) *Active Galaxies* (3 lectures), March 16 – 20, 2021, Course on Introductory Astronomy and Astrophysics for College Teachers, TLC, IUCAA.

Nishant K. Singh

Fluids and Plasma Physics (3 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, May 19, 20, 21, 2020.

Raghunathan Srianand

Stellar Structure and ISM (3 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, May 13, 15, 2020.

Kandaswamy Subramanian

Structure Formation in the Universe (3 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, May 26, 27, 28, 2020.



Durgesh Tripathi

Solar Physics (2 lectures), Introductory Summer School, and Refresher Course in Astronomy and Astrophysics, IUCAA, May 18, 2020.

(h) POPULAR/PUBLIC LECTURES (Online)

Dipankar Bhattacharya

Electromagnetic View of Cosmic Explosions, Kritika, IIT – Bombay, Mumbai, December 18, 2020.

Astronomy from Space - The India Story, Vigyan Yatra, India International Science Festival, NIPGR, New Delhi, December 21, 2020.

From Big Bang to Quarks - Exploring the Universe from Space, International Conference on Five Years of AstroSat, ISRO, Bengaluru, January 20, 2021.

Synchrotron Radiation in the Universe, National Science Day Workshop, BARC, Mumbai, February 25, 2021.

Weighing the Invisible: Profiling the Central Black Hole in the Milky Way, National Science Day, IUCAA, February 28, 2021.

Debarati Chatterjee

From Nuclei to Neutron Stars: Probing Nuclear Matter, Horizon Astronomy Club, IIT – Madras, Chennai, September 13, 2020.

Future Opportunities for Indian Girl Students in Mega-Science Project: LIGO – India, Nehru Science Centre, Mumbai, March 3, 2021.

Pratik Dabhade

Tuning to Mysteries of the Universe, Antariksh: Astro Club, VIT, Pune, June 6, 2020.

Sanjeev V. Dhurandhar

Gurutviya Laharin che Adbhut Vishva (Marathi), Parbhani Astronomical Society, November 22, 2020.

Shivaraj Kandhasamy

Gravitational Waves: A New Window to the Universe, Vidhyaa Giri College of Arts and Science, Karaikudi, May 27, 2020.

Accomplishing the Impossible: Detection of Gravitational Waves, Antariksh: Astro Club, VIT, Pune, August 1, 2020.



Neeraj Gupta

Square Kilometer Array (SKA): The Largest Radio Telescope, National Science Day, IUCAA, February 29, 2021.

Ranjeev Misra

The Nobel Road to Observing Black Hole Systems, IAR, Gandhinagar, October 2020.

Sanjit Mitra

Ripples in Space Time, Q & A Session, Astro Kerala, August 21, 2020.

Gravitational Wave Astronomy: The Grand Beginning and Future Prospects, Akashganga Astro Week, IISER, Pune, March 3, 2021.

Anupreeta More

Beyond the Earth, CM International School, Pune, July 11, 2020.

Unravelling the Dark Side of the Universe with Gravitational Lensing, Launchpad, Pune, July 26, 2020.

Dark Matter Day, Panel Discussion, IUCAA, October 31, 2020.

Aseem Paranjape

Dark Matter Day, Panel Discussion, IUCAA, October 31, 2020.

Dhurba J. Saikia

A Few Thoughts on Education and Tribal Development, North-East India: Innovative Tribal Development Strategies with Special Reference to Tripura, Association for Social and Human Advancement and ICFAI University, Tripura, June 30, 2020.

Scientific Temper and Society, Kokrajhar Government College and Assam College Librarians' Association, August 7, 2020.

On the Importance of Reading Literature, Orientation Programme, Department of English, Tezpur University, November 3, 2020.

Liberal Education and the Challenges of Institution Building, Workshop on National Education Policy, IIT – Bombay, Mumbai, November 10, 2020.

Nishant K. Singh

Magnetic Fields in Universe: Galaxies to Helioseismology - Current Trends in Research and Career Scope, Current Trends in Physics, Diamond Jubilee Year, Department of Physics, S. D. College, Alappuzha, November 21, 2020.



(i) RADIO/TV PROGRAMMES

Debarati Chatterjee

Femmes de Sciences, Interviewed by French Newspaper, Paris-Normandie, Podcast (in French), September 7, 2020.

Listening to the Cosmos, Interviews (4) of International GW Scientists, LI-EPO Podcast Launched, December 31, 2020, <https://www.ligo-india.in/podcasts/>

Anupreeta More

Sakhi Saheli, Interview, Vividha Bharati, Pune, March 24, 2020

Jayant V. Narlikar

Majhi Vasundhara (My Earth), Department of Environment and Climate Change, Government of Maharashtra on @majhivasundhara and @MitiGroup Facebook, February 4, 2021.



SCIENTIFIC MEETINGS & OTHER EVENTS

Introductory Summer School and Refresher Course in Astronomy and Astrophysics

The Introductory Summer School, and Refresher Course in Astronomy and Astrophysics was organized together, by IUCAA during May 11 - June 12, 2020. Surhud More, Aseem Paranjape, and Nishant Singh were the faculty coordinators. The set of lectures can be found online at <https://tinyurl.com/issa2020-playlist>.

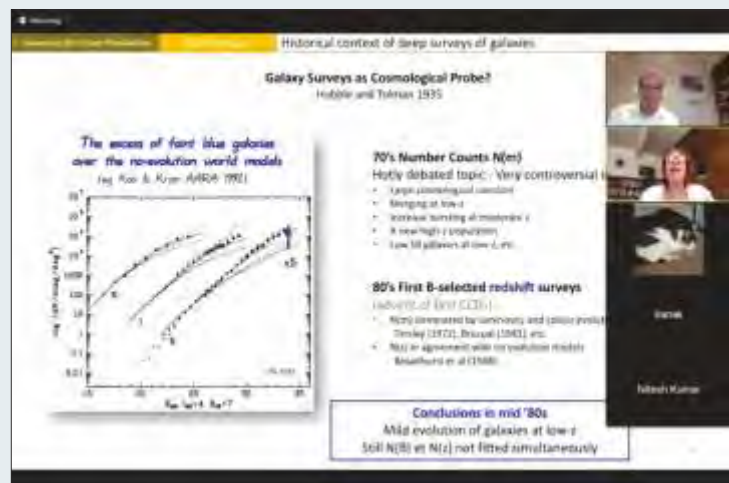
(For details, see Khagol, No. 123, July 2020)

Indo – French Astronomy School



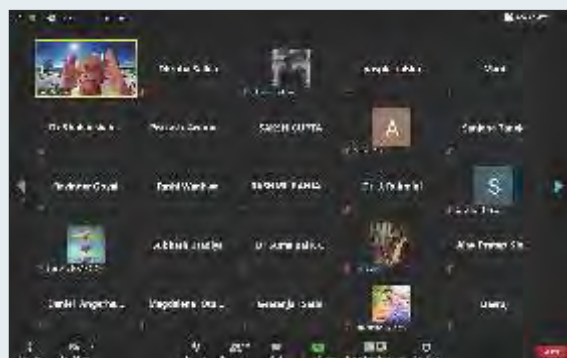
The Indo – French Astronomy School (IFAS – 6) was held during July 9–17, 2020, fully online, with the support of CRAL, LIO, and IUCAA. The directors of the school were: Philippe Prugniel (CRAI, France), and Kanak Saha (IUCAA). The IFAS– 7 has been planned in IUCAA, tentatively during July 29–August 6, 2021.

(For details, see Khagol, No. 124, October 2020)





Astronomy Centre for Educators



Teaching Learning Centre and National Resource Centre

An Introduction to Optical and Infrared Interferometry

An online course titled An Introduction to Optical and Infrared Interferometry, was organized by the Teaching Learning Centre of the Astronomy Centre for Educators, IUCAA, from the end of July 2020 till the end of September 2020 with Jean Surdej (Honorary Director, Extragalactic Astrophysics and Space Observatories Group, University of Liege, Belgium) as the instructor. This course was coordinated by Prakash Arumugasamy (IUCAA).

Inter-University Centre for Astronomy and Astrophysics
Astronomy Centre for Educators (ACE)
Teaching Learning Centre (TLC)
With support from the PMMMMTT scheme, MHRD.

INTRODUCTION TO OPTICAL AND INFRARED INTERFEROMETRY

(A short online course for
faculty members,
postdoctoral fellows
and research scholars)

Last date of registration: 23rd July 2020
Starting date of course: 27th July 2020
Ending date of course: 31st October 2020.

The lectures will provide a general
introduction to optical/IR interferometry,
including a brief history, a presentation of
the basic principles, some important
theorems and relevant applications.

by Prof. Jean Surdej
University of Liege

For registration follow the link: <https://bit.ly/TLCInterferometry2020>
For any queries please contact: nrciucaa@gmail.com

(For details, see Khagol, No. 124, October 2020)

The Thirty-Second Foundation Day Lecture

War and Peace: Conflict and Cooperation in an Insect Society





The 32nd Foundation Day Lecture of IUCAA was delivered on Tuesday, December 29, 2020, by Professor Raghavendra Gadagkar, DST Year of Science Chair Professor at the Centre for Ecological Sciences, Indian Institute of Science, Bengaluru. Due to the ongoing pandemic, the lecture was held entirely online, with a live YouTube stream that drew in about 370 viewers as well as a smaller, interactive audience on Zoom.

(For details, see Khagol, No. 125, January 2021)

Astronomy Centre for Educators Teaching Learning Centre and National Resource Centre Radio Astronomy Winter School

The thirteenth Radio Astronomy Winter School (RAWS – 2020) was organized online jointly by IUCAA and NCRA-TIFR, during December 28, 2020 – January 9, 2021. The core organizing group consisted of Ashish Mhaske, Avinash Deshpande, Dhruba J.Saikia, Jameer Manur, and Prakash Arumugasamy (all from IUCAA), and Ruta Kale and Subhashis Roy (both from NCRA-TIFR).

(For details, see Khagol, No. 125, January 2020)



Annual Refresher Programme in Teaching: ARPIT – 2020



A course on Stars and Stellar Systems, consisting of 36 video presentations separated into 10 modules on varied aspects of stars and stellar evolution was made by NRC of IUCAA for ARPIT - 2019. A total of 732 participants have registered for the course before the deadline of December 31, 2019. The course has been coordinated by Dhruba J.Saikia (IUCAA).

(For details, see Khagol, No. 125, January 2021)



Astronomy Centre for Educators

Teaching Learning Centre and National Resource Centre

Advanced Course on Pulsar Astrophysics



An online Advanced Course on Pulsar Astrophysics for faculty members, post-doctoral fellows and research scholars working in the field, was held during January 25 – April 10, 2021. The course was coordinated by Prakash Arumugasamy (IUCAA).

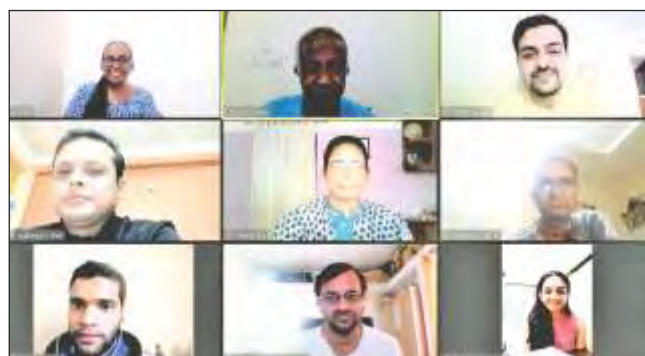
(For details, see Khagol, No. 126, April 2021)



Interactions with ARPIT 2020 Participants

An interaction session of the ARPIT 2020 participants with the resource persons was scheduled on each Sunday of March 2021.

(For details, see Khagol, No. 126, April 2021)



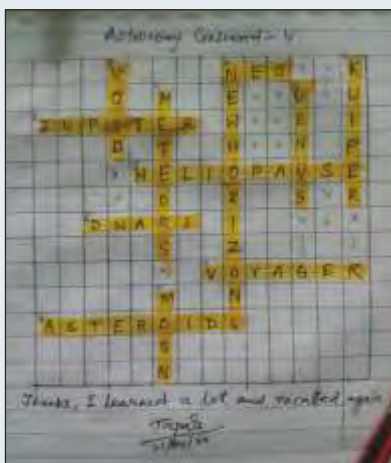


PUBLIC OUTREACH HIGHLIGHTS

Astronomy Crosswords

Starting mid-April 2020 to the first-week of May 2020, themed Astronomy Crosswords in English and Marathi were designed and shared with general public once a week, on different social platforms like Facebook, Twitter, and WhatsApp. The activity was designed and coordinated by Sonal Thorve (IUCAA).

(For details, see Khagol, No. 123, July 2020)



Story with a Science Toy



A series of stories of 20 scientists, each story followed by a simple toy explaining some related science concept to the story was published during April - June 2020. The activity was designed and coordinated by Shivani Pethe (IUCAA).

(For details, see Khagol, No. 123, July 2020)



Moon Challenge

In order to keep general public occupied with sky related activities during the lockdown, we presented them a "Moon Challenge", in which they have to look at the Moon at least once every day, over one complete lunar cycle of phases, i.e., from one new moon to the next. The SciPOP team also did this at the same time. Starting April 23, 2020, many people joined in this, and strived to be with us through the whole lunar cycle. The event was conducted by Samir Dhurde (IUCAA) with the help of Atharva Pathak, and was actively helped with regular telescopic pictures of the Moon by amateur astronomers Revati Dokhe, Anirudh Thakar, and Prabhakaran Kutti.

(For details, see Khagol, No. 123, July 2020)

Zero Shadow Day

To make it a nationwide celebration, a series of short animated videos explaining the concept of Zero Shadow Day in English and Marathi was published in early May 2020.

(For details, see Khagol, No. 123, July 2020)





Lectures on Introduction to Astronomy and Astrophysics, and Careers

Astronomy webinars were organised by different schools and colleges, in which Sonal Thorve was invited as a guest lecturer. On May 3, 2020, a lecture was organised by Teach for India, Ahmedabad, for school students. On May 17 and May 24, 2020, lectures for engineering and science students were organised respectively by Nutan Maharashtra Institute of Engineering and Technology, Talegaon, and the University of Delhi.

(For details, see Khagol, No. 123, July 2020)

Online Summer Astronomy Camp

School Students' Astronomy Camp was conducted online during June 1 – 6, 2020. Along with the introduction to hands-on astronomy projects, an introduction to upcoming solar eclipse, and how to observe it safely were given. The camp was coordinated by Sonal Thorve, and was succeeded in reaching about 1,000 students and astronomy lovers.

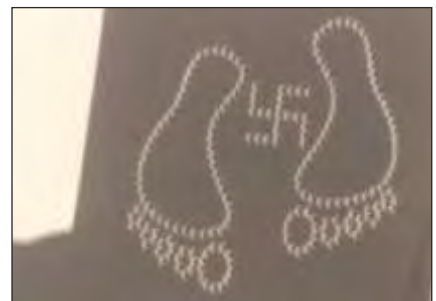
(For details, see Khagol, No. 123, July 2020)

Sessions on Annular Solar Eclipse Awareness

To spread awareness about the beautiful celestial event, the Annular Solar Eclipse on June 21, 2020, that was to be visible from all parts of India, sessions of webinars were conducted during June 5 – 17, 2020, by IUCAA SciPOP, with support from Vigyan Prasar, New Delhi. Tushar Purohit (IUCAA) was invited as the resource person.

(For details, see Khagol, No. 123, July 2020)





Annular Solar Eclipse

The residents of the IUCAA campus enjoyed the moments of the Annular Solar Eclipse on June 21, 2020, and also the online show put together collaboratively by IUCAA SciPOP and the ASI-POEC. The team for this event had Ishan Shinde and Atharva Pathak working from IUCAA, while Sonal Thorve and Ankit Bhandari from the core team, along with the rest of the SciPOP team were working in the background from their homes.

(For details, see Khagol, No. 123, July 2020)





Sci-Fi Enterprise

IUCAA SciPOP team organised the ‘Sci-Fi Enterprise: An online Science Fiction Story and Poetry Competition amidst lockdown’, which was a new and unique initiative to engage the public in science and astronomy. The event was designed and coordinated by Sonal Thorve (IUCAA).

Following this, we highlighted all the 7 winners and their creativity for a week, and again we received amazing responses from our audience. The event was designed and coordinated by Samir Dhurde and Shivom Gupta (both from IUCAA).

(For details, see Khagol, No. 123, July 2020)

Introduction to the Night Sky

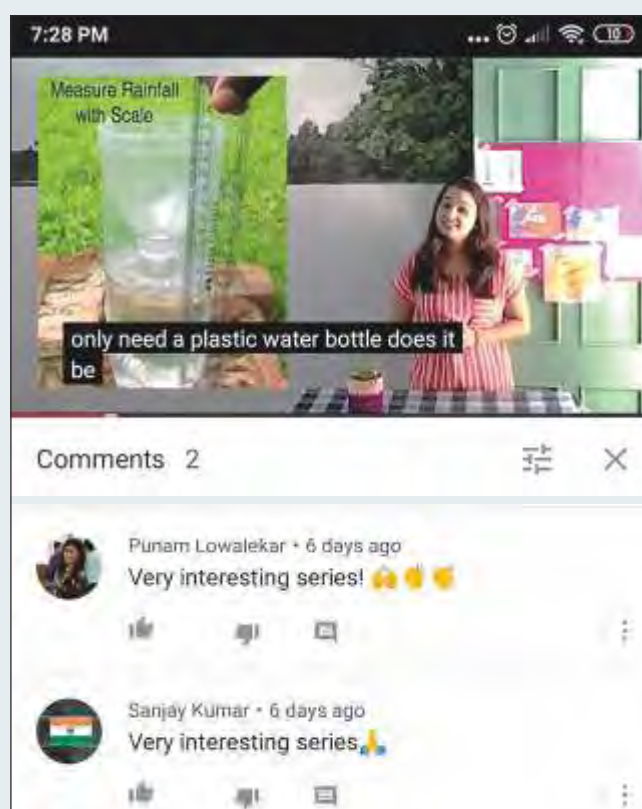
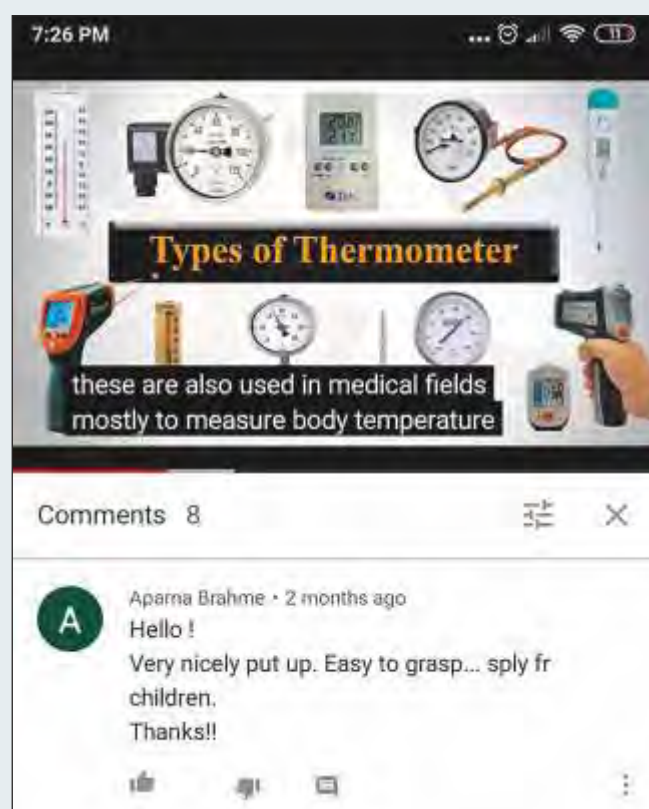
Facebook live sessions of Introduction to Night Sky were organised during June 27 – 28, 2020, by the Explorers Trekking Club, Pune. Tushar Purohit was invited as the resource person.

(For details, see Khagol, No. 123, July 2020)

Introduction to Basic Measuring Instruments

Starting from July 22 to September 23, 2020, videos in series were premiered on every Wednesday. The activity was designed and coordinated by Shivani Pethe (IUCAA).

(For details, see Khagol, No. 124, Oct 2020)





Webinars

The following Astronomy webinars on different topics were organised at different institutes with Sci POP resource persons as guest speakers:

July 16, 2020: Sonal Thorve on Introduction to Astronomy and Future Career Opportunity, at ABHAV Foundation, Chhattisgarh.

July 23 and 26, 2020: Rupesh Labade on Scientific Toys in Science Education in a Teachers' Training organised jointly by Agastya International Foundation and DIET, Pune.

July 26, 2020: Sonal Thorve on Astronomy – Exploring Time and Space, as a part of the lecture series “The Space Scientists”, organised by Jansona Institute of Technology, Coimbatore, jointly with Galileo Science Club, Tamil Nadu.

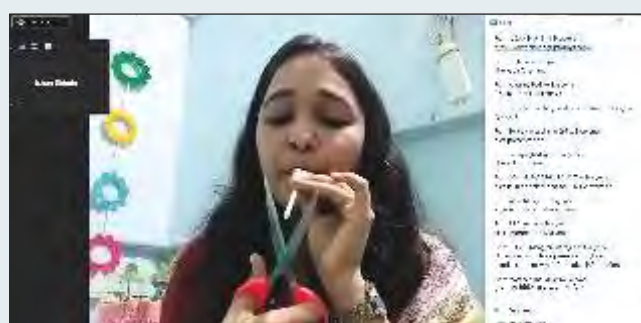
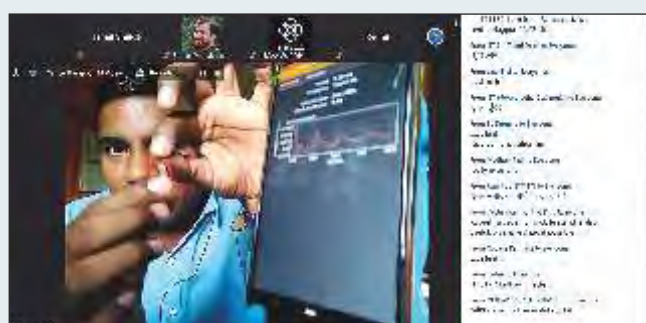
September 26, 2020: Samir Dhurde on Moon Challenge: A Close-up View, on the occasion of International Observe the Moon Night 2020, at the Rajasthan Department of Science and Technology.

(For details, see Khagol, No. 124, Oct 2020)

Online Teachers' Training

State level Online Teachers' Training was conducted during August 8 – 9, 2020. The training was coordinated by Rupesh Labade, and Sonal Thorve.

(For details, see Khagol, No. 124, Oct 2020)



Global Hands-on Universe Conference

The goal of the Global Hands-on Universe (GHoU – 2020) Conference was to train teachers on the use of modern tools and resources for science education and engage students in international scientific projects, and was conducted online during August 22 – 28, 2020.

(For details, see Khagol, No. 124, Oct 2020)





Revisiting Second Saturday Lecture / Demonstration with Live Interaction

A series – Revisiting IUCAA Lectures with live Q&A with the speaker is started. In this series, the following interactions were revisited:

September 12, 2020: Talks on Artificial Intelligence in Astronomical Research, by Kaustubh Waghmare (in English), and Kaushal Sharma (Hindi). Kaushal Sharma (ARIES)

interacted with the audience answering their questions live.

September 26, 2020: Taking the opportunity of International Observe the Moon Night, talk on Moon and Non-Rocket Science of it, by Samir Dhurde, followed by a live interaction.

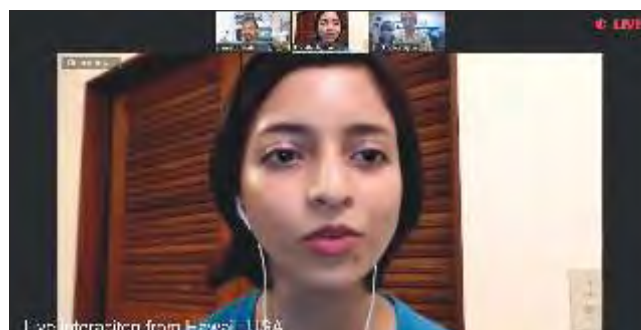
(For details, see Khagol, No. 124, Oct 2020)

MViSa

As part of IUCAA's efforts to support amateurs astronomy, a fortnightly series of lectures is being organised. The effort is being coordinated by Samir Dhurde.

The first lecture on 27 September, 2020 was about PANOPTES (Panoptic Astronomical Networked Observatories for a Public Transiting Exoplanets Survey) - a citizen science project that aims to make it easy for anyone to build a low cost, robotic telescope, to be used to detect transiting exoplanets.

(For details, see Khagol, No. 124, Oct 2020)



List of Public Talks by IUCAA Members

May 16, 2020: Primordial Black Hole: Black Holes from the Big Bang, by Swagat Mishra.

May 23, 2020: Introduction to Astrophotography, by Jameer Manur.

June 6, 2020: Tuning to Mysteries of the Universe, by Pratik Dabhade.

July 18, 2020: Do Your Own: Fun with Variables and Transients, by Ashish Mahabal.

July 26, 2020: Unravelling the Dark Side of the Universe with Gravitational Lensing, by Anupreeta More.

August 1, 2020: Accomplishing the Impossible: Detection of Gravitational Waves, by Shivaraj

Kandhasamy.

These talks were organized by Antariksh Astro Club, VIT, Pune, and were part of a series of online astronomy talks by astrophysicists from various renowned institutes, including IUCAA.

August 24, 2020: Inflation, Quantum Fluctuations and Primordial Black Holes, by Swagat Mishra, for the Astronomy Club, NISER, Bhubaneswar.

August 30, 2020: Exploring Inflationary Cosmology, by Swagat Mishra, for Naxxatra Science, India.

(For details, see Khagol, No. 124, Oct 2020)



LIGO – India Education and Public Outreach (LIEPO) Activities

GW@Home with LIGO – India Online Live Video Lecture Series

The LIEPO team was one of the earliest to conceptualise and implement “GW@Home with LIGO – India” - an online live video lecture series of 32 talks after the lockdown began. The first series started from April 1, 2020, and was hosted on the - LIGO India Education and Public Outreach YouTube Channel. The second series “GW@Home-2 with LIGO-India” ran during July 1– August 28, 2020. The speakers were organised by Sanjit Mitra (IUCAA) and the activity was coordinated by Vaibhav Savant (IUCAA) with support from Samir Dhurde (IUCAA) for live streaming the talks.

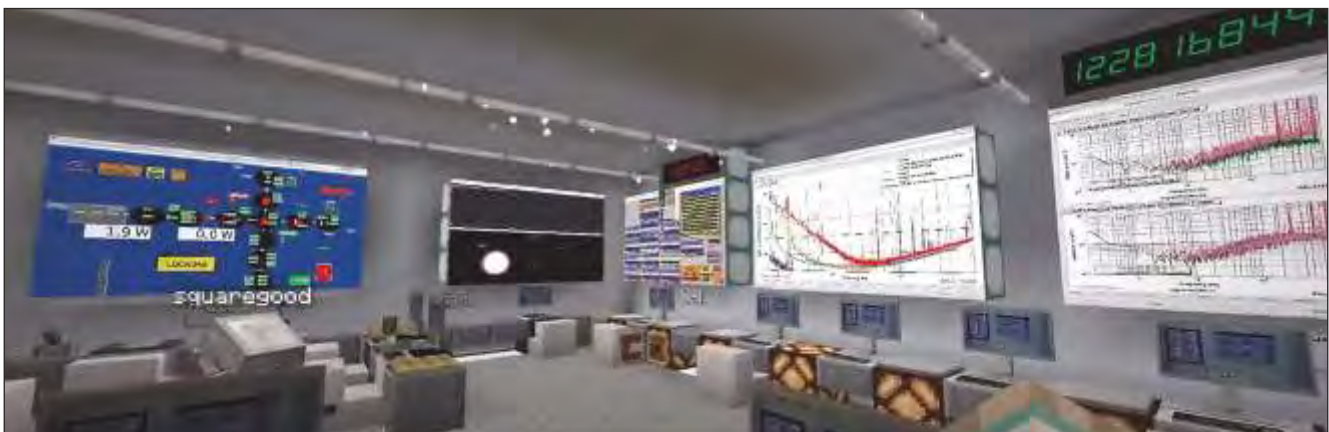
(For details, see Khagol, No. 124, Oct 2020)



Virtual Tour of LIGO in Minecraft

On the occasion of the fifth anniversary of GW150914, the first gravitational-wave detection by LIGO, LIEPO and ARC Centre of Excellence for Gravitational Wave Discovery (OzGrav) jointly conducted an exciting live virtual tour of LIGO in Minecraft - a sandbox video game about placing blocks, on September 15, 2020. The activity was coordinated and conducted by Vaibhav Savant and OzGrav colleagues.

(For details, see Khagol, No. 124, Oct 2020)





Pravega

As part of Pravega, the Indian Institute of Science annual TechFest, Somak Raychaudhury (Director, IUCAA) and Varun Bhalerao (Assistant Professor, IIT – Bombay, Mumbai) delivered invited talks in the Paradigms and the Coherence lecture series respectively. The talks were coordinated by Ankit Bhandari (IUCAA), and conducted by Pravega collaborators.

(For details, see Khagol, No. 124, Oct 2020)



Gravity Matters : Student Blog

On September 14, 2020, the launching of a gravitational waves (GW) related student blog called “Gravity Matters” was announced on the occasion of the fifth anniversary of the first direct detection of GW150914. The activity is being coordinated by Debarati Chatterjee (IUCAA).

(For details, see Khagol, No. 124, Oct 2020)

World Space Week

On the occasion of World Space Week, during October 3 – 10, 2020, themed Satellites Improve Life - Awareness Programme, IUCAA SciPOP released a series of posters on social media platforms promoting WSW – 2020 followed by posters explaining different satellite applications (in brief) for improving our lives, each day. The activity was designed and coordinated by Sonal Thorve (IUCAA).

(For details, see Khagol, No. 125, January 2021)

National Level Online Teachers' Training

To inaugurate the celebration of World Space Week 2020, a National Level Online Teachers' Training was conducted during October 3 – 4, 2020. The activity was designed and coordinated by Rupesh Labade (IUCAA).

(For details, see Khagol, No. 125, January 2021)

All-India Asteroid Search Programme

All-India Asteroid Search Programme was organised, during October 9 – November 3, 2020, by Ignited Minds-SKYAAC Saptarishi India Asteroid Search Campaign, in collaboration with the Vigyan Prasar, Government of India, and IUCAA SciPOP. Tushar Purohit (IUCAA) was a mentor for this online programme, at which totally 89 preliminary discoveries have been done as per the campaign records.

(For details, see Khagol, No. 125, January 2021)



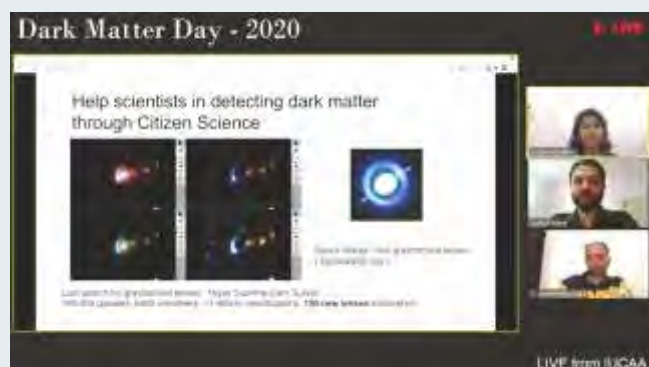
SAAO Astrofest

The South African Astronomical Observatory (SAAO), during October 20 – 23, 2020, celebrated its 200th birthday, and unveiled as a National Heritage site on the first day. Samir Dhurde (IUCAA) conducted a workshop on Mastering Astronomy, with Sonal Thorve, on October 22.

(For details, see Khagol, No. 125, January 2021)



Dark Matter Day



Dark Matter Day is an international event, that aims to shed light on the mystery on Dark Matter. From 2020, October 31 is celebrated as the 'Dark Matter Day' worldwide, which spreads the word about the many fascinating ways scientists search for Dark Matter, and the importance of devoting scientific resources to unravel this cosmic riddle.

(For details, see Khagol, No. 125, January 2021)

PuLastya Science Festival

To cherish the relationship of late Shri. P. L. Deshpande and his wife, late Smt. Sunitabai Deshpande with IUCAA, the PuLastya Science Festival has been celebrated annually, and this year, it was celebrated during November 7 – 8, 2020 virtually. The event was hosted and coordinated by Sonal Thorve.

(For details, see Khagol, No. 125, January 2021)





Diwali Special Video Series

A Diwali Special Video Series was released, during November 16 – 21, 2020, on the occasion of festival of lights. The activity was designed and coordinated by Rupesh Labade.

(For details, see Khagol, No. 125, January 2021)



Maitri Bhoogolashi



In collaboration with the District Institute of Education and Training, Thane, Maharashtra, an online teachers' training was organised by IUCAA SciPOP, on November 18 and 20, 2020. Sonal Thorve was the resource person, who also designed and coordinated with the help of DIET, Thane.

(For details, see Khagol, No. 125, January 2021)

Workshop on Teaching Science and Astronomy



IUCAA SciPOP in collaboration with the Astronomy Club, Department of Science Education, Samtse College of Education, Bhutan, organised a Workshop on Teaching Science and Astronomy on December 7, 2020, for teachers. Samir Dhurde and Sonal Thorve were the resource persons, and was coordinated by the former.

(For details, see Khagol, No. 125, January 2021)



SciFunZone

An online, live interaction activity named, SciFun Zone was started from December 8, 2020, and it would be a 10 week long Toy Story with Science activity till the end of February 2021, with about 400 school students of classes 5 to 9 participating from home. The activity is being coordinated by Shivani Pethe.

(For details, see Khagol, No. 125, January 2021)

IAUS367: Education and Heritage in the Era of Big Data in Astronomy



The primary goal of the International Astronomical Union Symposium 367 (IAUS 367) held online during December 8 – 12, 2020, was to give a global vision of Education and Heritage in the frame of the goals of the IAU.

(For details, see Khagol, No. 125, January 2021)





Workshop on Telescope Making

Zilla Parishad (ZP) School Ternanager, Osamanabad; and Latur Science Center, in Maharashtra, organised a Workshop on Telescope Making for ZP school teachers at Kasbe, Tasa, Wala, Osmanabad, on December 18, 2020.

(For details, see Khagol, No. 125, January 2021)



Astronomy and Telescope Handling Workshop



Discovery Science Centre, Kerwadi, Parbhani; Government Ashram Shala, Osmanabad; and Government Ashram Shala, Jintur, in Maharashtra have set up small science centres at various schools in different regions. They organised teachers training programmes at Ashram School, Osmanabad, on December 23, 2020, and at Ashram School, Akali, Jintur, on December 24, 2020. Tushar Purohit was invited to conduct the Astronomy and Telescope Handling Workshop.

(For details, see Khagol, No. 125, January 2021)

Webinars

Following lectures by IUCAA personnel were organised during December 3 – 9, 2020 as part of the Basic Course in Practical Astronomy, at the Jyotirvidya Parisanstha, Pune:

October 8, 2020 – Sonal Thorve, on Nobel Prize in Physics 2020, at MSS High School, Chinchwad, Pune.

October 8, 2020 – Tushar Purohit, on History of Telescopes, at Kaylan Pradeshik Lok Vigyan Kendra, Bhavnagar, Gujarat, as part of World Space Week celebrations.

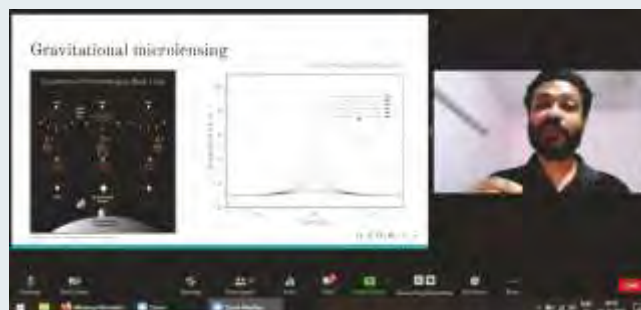




October 10, 2020 – Tushar Purohit, on Observing Meteor Shower, at Smart Circuits Innovation, Chandigarh, as part of World Space Week celebrations.

December 17, 2020 – Samir Dhurde, on Try Out Planetary Science Yourself, at Nehru Science Centre, Mumbai.

(For details, see Khagol, No. 125, January 2021)



Revisiting Second Saturday Lecture Demonstration with Live Interaction

October 10, 2020 – Surhud More, on Hunting for Planet 9 (in English). He also interacted with the audience answering their questions live.

(For details, see Khagol, No. 125, January 2021)



MViSa Talks



November 1, 2020 – Ted Blank (International Occultation Timing Association), on Chasing Shadows: Citizen Science Opportunities in Occultation Recording.

December 6, 2020 – Karl Antier (International Meteor Organisation), on Research the Solar System with Shooting Stars.

December 6, 2020 – Arvind Paranjpye (Nehru Planetarium, Mumbai), on Recording Meteor Showers: Live Simulations and Training.

December 13, 2020 – Peter Jenniskens (Principal Investigator of the Cameras for All Sky Meteor Surveillance Project, SETI Institute, NASA, USA), on Tonight's Geminids and Other Meteor Showers over India.

(For details, see Khagol, No. 125, January 2021)



LIGO-India Education and Public Outreach (LIEPO) Activities

Listening to the Cosmos: Podcast Series

A podcast series titled: Listening to the Cosmos, was launched on October 2, 2020 as part of the Gravity Matters blog by LIGO-India. The activity is being coordinated by Debarati Chatterjee (IUCAA).

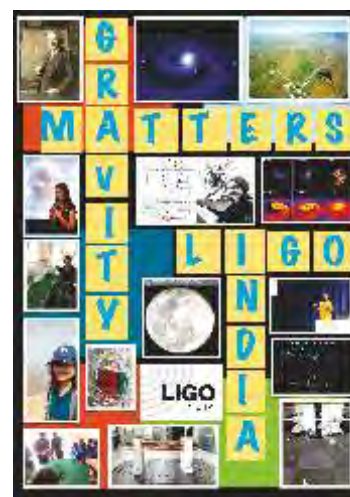
(For details, see Khagol, No. 125, January 2021)



Gravity Matters: Blog on Gravitational Waves

On the eve of the new year December 31, 2020, LIEPO published the much awaited blog on gravitational waves (GW) called: Gravity Matters, on their website (www.ligo-india.in/gravitymatters/). The activity is being coordinated by Debarati Chatterjee.

(For details, see Khagol, No. 125, January 2021)



International Association of Physics Students Webinar

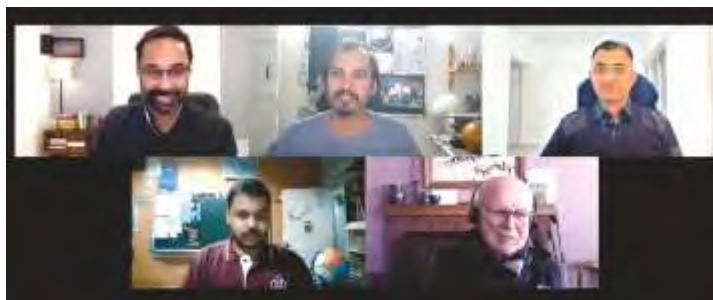
Suresh Doravari (IUCAA) conducted a webinar on Experimental Opportunities Related to Gravitational Wave Detectors in India, on October 11, 2020, and was organised by the Delhi Local Committee of the International Association of Physics Students. The activity was coordinated by Vaibhav Savant (IUCAA).

(For details, see Khagol, No. 125, January 2021)



Interview given by Professor Rainer Weiss

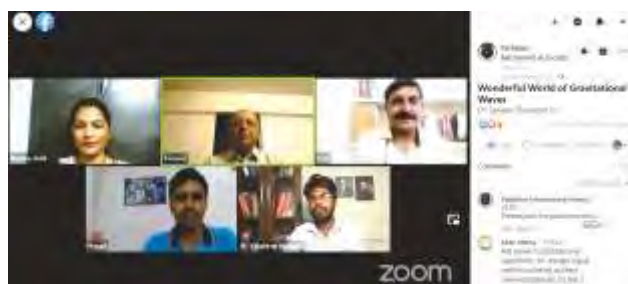
On the occasion of the birth anniversary of Nobel Laureates Professor Marie Curie, and Sir C. V. Raman, a unique interview with the 2017 Nobel Laureate in Physics, Professor Rainer Weiss (Professor of Physics, Emeritus, MIT, USA) was organised on November 7, 2020, by LIEPO on their YouTube Channel. This activity was coordinated by Vaibhav Savant.



(For details, see Khagol, No. 125, January 2021)

New Career Options

LIEPO and Parbhani Astronomical Society jointly organised an online talk by Sanjeev Dhurandhar (IUCAA), on November 22, 2020, as part of the online lecture series: New Career Options (करियरच्या नव्या वाटा), initiated for regional students. The activity was coordinated by Ankit Bhandari.



(For details, see Khagol, No. 125, January 2021)



SciFunZone

This online activity started from December 8, 2020 and continued till the National Science Day, February 28, 2021, and conducted in collaboration with the schools in Goa. This activity was coordinated and conducted by Shivani Pethe (IUCAA).

(For details, see Khagol, No. 126, April 2021)

Training Programmes for Teachers by Science Centres

On January 18, 2021, Discovery Science Centres at Kerwadi, Parbhani, and the Government Ashram at Naigaon, near Nanded, had set up small science centres at various schools in the regions, and organised an one day training programme for school teachers at the Government Ashram School at Naigaon.

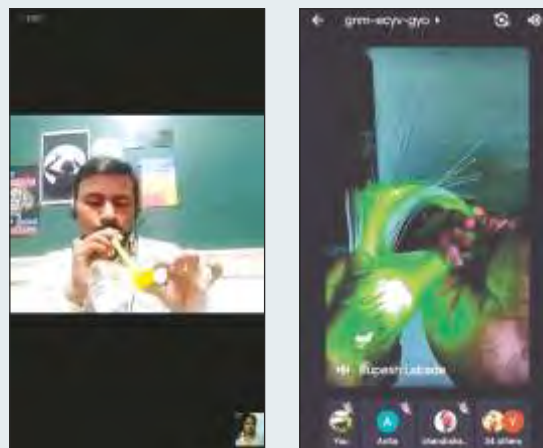
Also, on January 19, 2021, there was another one day training programme for teachers at the Dreamland School, Kerwadi. Twenty teachers participated in this training. Tushar Purohit (IUCAA), conducted both the training programmes and sessions teaching the basics in Astronomy and telescope handling.

(For details, see Khagol, No. 126, April 2021)

Training Programme for Teachers

- (I) A Training Programme for Teachers on Science and Astronomy teaching methods was organised on February 14, 2021, at the MES Rani Laxmi Bai Mulinchi Sainiki Shala, Pirangut, Pune. Rupesh Labade and Sonal Thorve (IUCAA) conducted the workshop.
- (ii) One Training Programme for Teachers of Baramati District. on March 12, 2021, and another such programme for teachers of Ahmednagar region, on March 22, 2021, were conducted by the Agastya International Foundation. Rupesh Labade was the coordinator and resource person.

(For details, see Khagol, No. 126, April 2021)



Workshops on Science Toys



- Organised on January 27, 2021, at the Vigyan Ashram, Pabal, under the programme named, 'Khel Khel Main', which is a scheme under the Vigyan Ashram, Pabal, and Muktangan Exploratory, Pune.
- Organised on February 25, 2021, at the VP's Vinod Kumar Gujar Bal Vikas Mandir. Around 80 students of class 8 participated.
- Conducted on February 26, 2021, at the Tilak Maharashtra Vidyalyaya, Tilak Road, Pune. There were 150 student participants of classes 1 to 5.

(For details, see Khagol, No. 126, April 2021)

National Science Day Competitions

This year, due to the Covid -19 pandemic, National Science Day competitions in IUCAA for school students were conducted online on February 20, 2021.

(For details, see Khagol, No. 126, April 2021)

National Science Day Celebrations

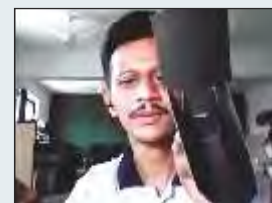
The National Science Day celebrations were conducted on February 28, 2021 online, due to the pandemic. The whole IUCAA team kept no stone unturned to celebrate the day as enthusiastically as every year.

(For details, see Khagol, No. 126, April 2021)



National Science Day Hands-on Session

On occasion of National Science Day, Jansons Institute of Technology, Coimbatore, and Galileo Science Club, Tamil Nadu, jointly organised an online hands-on session for teachers and students on February 28, 2021. More than 200 participants attended the session. Tushar Purohit gave a talk on basic Astronomy, and conducted the hands-on activities.



(For details, see Khagol, No. 126, April 2021)

National Science Day Celebration Week

A series of videos was launched for 6 days after the National Science Day to compensate for the on ground celebrations as every year.

March 1, 2021: Science Toys Demonstrations: These were given by the school students of different schools in Goa. The event was coordinated by Shivani Pethe.

March 2, 2021: IUCAA Share Science Drive Reference: The aim of this initiative was to create short science videos in all possible regional languages of India with the help of schools, and trying to make science interesting for all. This initiative was coordinated by Sonal Thorve.

March 3, 2021: Ideas Behind Winning Drawings (Inter-School Competitions): The top 3 drawings were displayed, and the prize winners shared the ideas behind their drawings.

March 4, 2021: Ideas Behind Winning Essays (Inter-School Competitions): The top 3 essays were displayed, and the prize winners shared the ideas behind their essays.

March 5, 2021: Ideas Behind Winning Poetries (Inter-School Competitions): The top 3 poems were displayed, and the prize winners shared the ideas behind their poems.

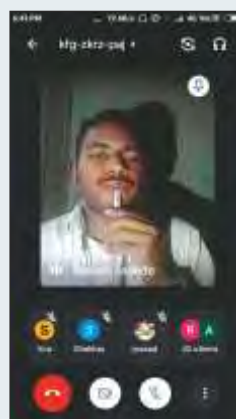
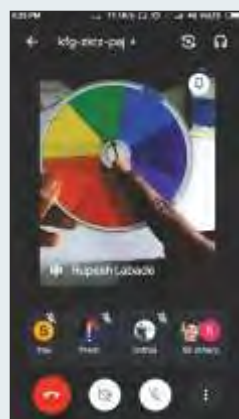
March 6, 2021: Future of Science-Technology-Innovation in India, expressed through Arts: Selective drawings and poetries in different Indian regional languages submitted as a response to the open call to the public to participate in National Science Day celebrations with IUCAA were featured.

(For details, see Khagol, No. 126, April 2021)

Experimental Demonstration on Scientific Concepts

A special session for Experimental Demonstrations on Scientific Concepts was organised on March 1, 2021, by the Agastya International Foundation. Ninety students of class 8 participated in the session. Topics like sound and light were covered, and Rupesh Labade conducted the session.

(For details, see Khagol, No. 126, April 2021)





Workshop on Astronomy and Zero Shadow Day

Swami Vivekananda Youth Movement, Mysore, in association with Vigyan Prasara, Noida, and IUCAA SciPoP, organised a Workshop on Astronomy and Zero Shadow Day, during March 24 – 27, 2021, at Dharwad, Karnataka. The resource person, Tushar Purohit gave a talk, and conducted the hands-on activities in the workshop.



(For details, see Khagol, No. 126, April 2021)

Talks Given by the SciPoP Team

January 13, 2021: Know our Universe, at Homi Bhabha Balvaidnyanik, Kankavli, by Sonal Thorve.

February 5, 2021: History of telescope, at Modern College, Ganeshkhind, Pune, by Tushar Purohit.

February 23, 2021: Sky watching and Astronomy, at C.T. Bora College, Shirur, by Tushar Purohit.

February 28, 2021: Sky watching, for Bhaskar Astro Association, by Tushar Purohit.

February 28, 2021: Citizen scientist in astronomy, organised by Vigyan Prasara, Noida, and Saptarshi India Asteroid Hunting Camp, by Tushar Purohit.

March 5, 2021: Use of toys in science education, at H.H.C.P. Huzurpaga Girls High School, Laxmi Road Pune, by Rupesh Labade.

(For details, see Khagol, No. 126, April 2021)

Revisiting Second Saturday Lecture Demonstration Programme with Live Interaction

February 13, 2021: Why study Astronomy?, by Jayant Narlikar (English).

March 27, 2021: Our place in space, by Somak Raychaudhury (English).

After each lecture demonstration, both the speakers interacted with the audience, and answered their questions.

(For details, see Khagol, No. 126, April 2021)

IUCAA Awesome Amateur Astronomy Talk Series

February 21, 2021: Amateur Planetary Observation and Contributions, by Sanjay Limaye, and Tim Robertson, and was coordinated by Samir Dhurde, and Atharva Pathak.

(For details, see Khagol, No. 126, April 2021)



PH.D. PROGRAMME

During the year of this report, three IUCAA Research Scholars namely: **Debjyoti Sarkar** (Guide: Tarun Souradeep), **Ruchika Seth** (Guide: Somak Raychaudhury), **Vidushi Sharma** (Guide: Dipankar Bhattacharya), have defended their Ph.D. theses. Their Ph.D. degrees have been awarded by the Jawaharlal Nehru University, New Delhi. The synopses of their theses are given below :

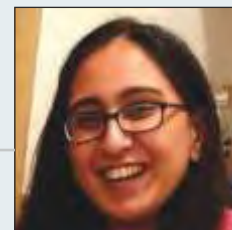
Debjyoti Sarkar

Study of CMB Spectral Distortions

In this thesis we present study of the Cosmic Microwave Background(CMB) spectral distortion and implication of measurement of spectral distortion on our understandings on the physics of the early universe. Among the various sources of spectral distortion, we mainly focus on the Cosmological Recombination. Precision measurement of the cosmological recombination spectrum can provide an entire new window to look at the early universe. We aim to quantify the information hidden in the cosmological recombination spectrum. For this purpose we have developed a new code following the effective conductance algorithm. Our code is closely based on the COSMOSPEC code. We find, using Fisher information matrix and assuming that the foregrounds can be subtracted by using higher or lower frequency channels and spatial information, that going beyond the detection will need an experiment with sensitivity $25\times$ better compared to the proposed experiment PIXIE. Such an experiment will be able to measure the cosmological parameters with a precision that is competitive with the CMB anisotropy experiments. The best constrained parameter is baryon energy density Ω_b which can be nailed down with incredible precision in principle. We also show that the shape of the hydrogen lines is connected to the speed of the Hydrogen recombination , with the peaks of the recombination lines coinciding with the peak of the recombination rate. In general, the shape of the lines encodes information about the rate of recombination as a function of redshift. We also presented a brief report on two ongoing projects: *i*) putting constraint on dark matter annihilation using cosmological recombination spectrum and *ii*) effect of Triple Compton process on the CMB spectral distortion.



Ruchika Seth



The evolution of galaxies on the cosmic web

Evolution of galaxies on the cosmic web deals with the story of the galaxies' life-cycle, particularly the shared relationship between their position on the cosmic web and their evolutionary state. Studying the overall evolutionary trend of a population of galaxies in a diverse and continuous range of environments is crucial for understanding the cause and effect of the interaction of galaxies among themselves as well as with the gas in the surrounding medium.

The galaxy-gas interactions can be essentially divided into two broad parts. The first part discusses the influence of the environment on the galaxies. The second part emphasises the role of feedback from a subset of galaxies affecting the surrounding medium. Various interaction phases of these systems involve physical mechanisms like ram-pressure stripping, tidal interactions, AGN-feedback etc.

Observations from the ground-based GMRT, Sloan Foundation 2.5m Telescope at Apache Point Observatory, and space-based Chandra, Spitzer, GALEX and WISE were employed to infer the activity of galaxies and studying the physical parameters of the hot gaseous content of the intergalactic medium (IGM).

Data from large-scale optical spectroscopic surveys such as Sloan Digital Sky Survey (SDSS), Dark Energy Camera Legacy Survey (DECaLS), and Arizona Cluster Redshift Survey (ACReS) are also employed, along with multiwavelength datasets of the LoCuSS survey, including wide-field imaging data from UKIRT/WFCAM to characterise the galaxy population in terms of their star formation, AGN activity, quenching, and optical morphology.

Galactic environment is characterised by the ambient IGM present in galaxy groups and clusters, physical parameters like temperature, pressure, shock fronts, cavities etc. offer dynamical insight of the various mechanical interactions disturbing the smooth gaseous morphology, while the overdensity of the underlying galaxy population characterises the underlying galactic environment. Particle content of radio plasma and AGN relics throws light on the AGN activity and at times the state of IGM. Interaction of radio plasma with turbulent IGM results in the phenomenon of AGN Pheonix/ relics in these systems.

Previous studies estimating the impact of the environment on galaxy evolution characterised the environment primarily from a unidimensional viewpoint. For example, some studies used the surface density parameter (Baldry et al.), overdensity parameter (Peng et al.), or group vs non-group (Wetzel et al.), group-centric distance or KDE (Haines et al.). Unlike other galaxy physical parameters (e.g., stellar mass, SFR, colour or AGN fraction) galaxy environment is a complex quantity to measure. Various parametrisation gives a different perspective on the environment. We employed a multi-dimensional view on the environment. In particular, we used a combination of KDE and group/non-group environment to characterise the Coma supercluster environment and study its dependence on other galaxy physical parameters. To achieve this, we take a spectroscopically complete sample from the SDSS spanning the entire



Coma supercluster. The environment is characterised using the (Yang et al. 2007) group catalogue, which is an optically-selected, volume-limited group catalogue which is based on the SDSS DR7 galaxy catalogue, and the large-scale environment is estimated using a kernel density estimator (KDE) algorithm, which is a non-parametric technique to calculate a probability density estimator.

We inspect the galactic population's impact on the environment particularly accessing the role of non-central radio galaxies towards the energetics of the IGM of rich galaxy clusters. The role of AGN in the central cluster ellipticals (BCGs) in heating the intergalactic medium has been well established. The powerful radio jets emanating from these galaxies are physically capable of displacing the IGM, carving a depression in the X-ray surface-brightness. For the first time, we inspect the role of the sub-powerful non-central galaxies present elsewhere in the cluster system, which might unanimously contribute towards feedback in such systems. We performed a statistical study of radio populations, especially those that were resolved and set upper limits for the unresolved ones; the total radio output in terms of the population's combined bolometric luminosity was also computed. The radio jet power is also computed from the extended sources and compared to their respective radio emissions. Although AGN feedback from the central galaxies seems to be a popular solution to the classical cooling flow problem, it fails to account for the efficient thermal conduction to the entire IGM. On the other hand, a sizeable radio-active galaxy population ($\sim 5\%$) is estimated to be present in the cluster of which many spheroids are known to be present within the cooling core. These spheroids can very well serve as secondary sources contributing towards more isotropic heating to the IGM. In this way, it would be a more convenient way to transfer energy to the IGM.

We also study an exclusive merger driven cluster system with detected cavities in the X-ray emission. The central hot gas in many cool-core systems is not distributed uniformly, but is displaced by forming cavities approximately coincident with lobes of extended radio emission. Such X-ray cavities have been detected in $\sim 70\%$ of the cool-core clusters, and this number could well be underestimated due to the limitation of cavity detectability.

Vidushi Sharma



Probing the central engine and early emission of Gamma-Ray Bursts

Gamma-Ray Bursts (GRBs) are the most energetic and distant sources in the cosmos. The initial brief ($\sim$ a few seconds) and intense flashes of gamma-rays outshine every other extreme energy source in the sky. These gamma-ray flashes originate close to the burst site and are known as prompt emission. Subsequently, the burst ejecta collide with the external ambient medium and radiate in all wavelengths (radio to gamma rays), known as afterglow emission. The duration of GRB prompt emission is characterized by the ' T_{90} '¹ parameter. Based on its value, GRBs are classified into 'short' (< 2 s) and 'long' (> 2 s) variants. Short GRBs (sGRBs) are thought to be produced by the merger of compact objects, like neutron star-neutron star (NS-NS) and neutron star-black hole (NS-BH), whereas long GRBs (lGRBs) are produced from the core collapse of massive stars. Both the variants result in the formation of a new black hole or a magnetar, and both can eject material in the form of relativistic jets.

In high energy astrophysics, some of the fascinating problems related to the nature of relativistic jets are: (a) How is the jet produced and accelerated to such high velocities? (b) What is the jet composition, is it a baryon-dominated or Poynting-flux-dominated outflow? (c) Where and how does the energy dissipation occur in the outflow, is it via internal shocks or magnetic reconnections? (d) Is the underlying emission process that gives rise to observed radiation, synchrotron or inverse Compton scattering? The powerful nature of GRBs makes them a very suitable candidate for probing the physics of relativistic jets. Therefore, it is also imperative to understand the nature of the central engine of the GRBs.

With the first coincident detection of gravitational waves with electromagnetic (EM) signals from GRB 170817A, the era of 'multi-messenger' astronomy has begun. It has also posed several key questions regarding: (a) The nature of post-merger remnant or central engine of GRBs; and (b) The jet profile of GRBs, or cocoon as an alternate model in case of faint GRBs detected in the nearby universe. In the case of sGRBs, produced by the NS-NS mergers, the total mass of the remnant/central engine is useful for ruling out some of the equations of state (EoS) in NS. Studying the radiation (EM) of sGRBs can play an important role to probe the above questions.

This thesis comprises of nine chapters and is broadly divided into two parts. A chapter-wise summary is presented as follows:



- The introductory part of the thesis contains two chapters.
 - In [Chapter 1](#), the physics of GRBs is briefly reviewed.
 - [Chapter 2](#) presents a basic overview of *AstroSat*/Cadmium Zinc Telluride imager (CZTI), *Fermi* Gamma-ray Space Telescope and Neil Gehrels *Swift* Observatories, and data from these have been used in the thesis.
- The first part of the thesis addresses questions concerning the nature of the jet and of the underlying radiation mechanism in the prompt phase.
 - [Chapter 3](#) reviews various models for early emission mechanism of GRBs.
 - [Chapter 4](#) examines the radiation mechanism in a bright GRB 160821A using remarkable polarisation measurements made by the *AstroSat*/CZTI along with simultaneous observations from *Fermi*.
 - In [Chapter 5](#), the emission mechanism in GRB 160325A is inferred using the spectrum and polarisation measurements along with afterglow observations.
- In the second part, the thesis focuses on understanding the nature of the central engine and its properties for both long and short GRBs.
 - In [Chapter 6](#), possible models of the central engine and their mechanisms are discussed.
 - [Chapter 7](#) discusses a search carried out to identify GRBs with black holes as central engines and presents its results.
 - [Chapter 8](#) describes an attempt to understand the central engine of sGRBs based on prompt emission spectrum.
- The concluding [Chapter 9](#) summarizes the results of the thesis, their implications and the outlook for the future.

A brief summary of part I and II of the thesis is presented below.

Part I: Emission Mechanism

The knowledge of temporal and spectral properties of GRBs has been enhanced significantly with the launch of dedicated space-based observatories like Neil Gehrels *Swift* and *Fermi*. Prompt and afterglow phases are being detected in multiple wavebands (X-rays and UV) via Burst Alert Telescope (BAT), X-Ray Telescope (XRT) & UltraViolet and Optical Telescope (UVOT) instruments on board Neil Gehrels *Swift* Observatory since 2004. BAT observes the source in the narrow energy band restricted to 15-150 keV. The *Fermi* mission, on the other hand, provides an energy coverage from 8 keV to ~ 300 GeV via onboard instruments, the Gamma-ray Burst Monitor (GBM) and the Large Area Telescope (LAT). Traditionally, the prompt emission spectra of GRBs are fitted with an empirical function, known as **Band** function, representing non-thermal emission. However, in some GRBs, deviation from the **Band** function has been observed. An additional or distinct component like a **blackbody** function (thermal



emission) or powerlaw or cutoff-powerlaw or smoothly broken-powerlaw with one or two breaks is found to improve the fit statistics significantly. Also, physical models of synchrotron and photospheric emission are directly found to fit the data. Currently, it is found that sometimes the same data can be fitted with different spectral models which provide equally good statistics. The spectroscopic study of prompt gamma-ray emission of GRBs provides valuable information, yet, it alone is inadequate to fully discriminate between various emission models. Therefore, there is a dire need for more constraining observables like polarisation. Different degrees of polarisation are expected from synchrotron radiation originating from magnetic field structures ordered on different scales and depending upon the viewing geometry of the jet. For inverse Compton and photospheric emission, a meagre polarisation fraction is predicted, except when the jet is viewed off-axis. Generally, some asymmetry in the emitting region or viewing geometry results in linearly polarised emission. Hence, the measurement of polarisation simultaneously with spectroscopy can break the degeneracy between various spectral models. Further, the variation of polarisation with time is an important tool for understanding the temporal dynamics of the jet.

The measurement of polarisation in X-ray astronomy is highly challenging for transient events like the prompt emission of GRBs mainly because of the scarcity of incident photons and the brevity of the event. Thus, to date, polarisation measurements have been attempted only for a handful of cases by the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI), INTErnational Gamma-Ray Astrophysics Laboratory (INTEGRAL), GAMMA-ray burst Polarimeter (GAP), the Cadmium Zinc Telluride Imager (CZTI) and POLAR, and most of the results have limited statistical significance. The CZTI, onboard *AstroSat*, is actively detecting GRBs in hard X-rays since its launch in September 2015. Currently, *AstroSat*/CZTI is the only space observatory, capable of measuring linear polarisation in the 100-400 keV energy band. For bright bursts with a significant number of Compton-scattered events in the detector, the linear polarisation measurements are promising. Therefore, the statistically significant polarisation measurements from *AstroSat*, along with simultaneous spectroscopic measurements, can be beneficial in the advancement of GRB physics.

Observations of the afterglows of GRB events can complement the spectro-polarimetric analysis by providing crucial information regarding radiative efficiency and the opening angle of the jet. Therefore, integrating all the information from prompt and afterglow phases using multi-mission data can help to build a comprehensive physical picture of the burst.

In [Chapter 3](#), a review on the various physical models for emission mechanisms in GRBs is presented. Distinct signatures in polarisation and spectral observations as predicted by different theoretical models are discussed. We describe how the measurements of polarisation simultaneously with spectroscopy can resolve the existing enigma of underlying radiation mechanism, composition, and the viewing geometry of the GRB outflow.

In [Chapter 4](#), the study of the time-resolved spectro-polarimetric analysis of the third most luminous gamma-ray burst, GRB 160821A, in the history of *Fermi* detections, is presented. Owing to its bright nature, the main episode of the burst observed by *AstroSat*/CZTI, recorded



the highest number of Compton events in the first two years of its operation. Analysis of polarimetric data from *AstroSat* and spectroscopic data from *Fermi* revealed that during the main emission episode of the burst, the position angle of the observed polarisation flipped orthogonally twice along with concurrent changes in the spectrum. The total emission exhibited a low polarisation fraction, $21^{+24}_{-19}\%$, due to the presence of the angle flips. However, the time-resolved emission showed a high linear polarisation. Thus, by taking into account the change in polarisation angle, we estimated an average linear polarisation fraction of $66^{+26}_{-27}\%$ across the burst. The spectrum of the burst was found to be best modelled using a combination of **blackbody + Band $\times$ Highecut** models. The high energy part of the spectrum was found to display significant variation with time. It was concluded that the observed emission is synchrotron radiation produced in ordered magnetic fields based on the following: (a) the large energy content of the burst implied that the jet was viewed on-axis, (b) a concurrent change in polarisation and high energy spectrum, (c) a high degree of linear polarisation, and (d) flipping of polarisation angle twice during a single emission episode (only such observation to date). Inverse Compton scattering and synchrotron emission produced in random magnetic fields were ruled out, as they would have produced a very weakly polarised emission for an on-axis observer. The chapter also presents the analysis of the precursor and afterglow emission, completing the observed properties of the burst.

In [Chapter 5](#), spectro-polarimetric analysis and physical modelling of the long bright GRB 160325A is presented, which is the only gamma-ray burst observed in the primary field of view of *AstroSat*/CZTI to date. It was also detected by Neil Gehrels *Swift* Observatory and *Fermi* Gamma-ray Space Telescope. The prompt emission of the burst consists of two distinct emission episodes separated by a quiescent/mild activity period. A Joint time-resolved spectral analysis performed on the first episode provides **blackbody (BB) + Cutoff-powerlaw (Cp1)** as the best-fit model. The Cp1 photon index (α) is found to increase with time and is greater than the line of death of synchrotron emission. This is in contrast to the classical fireball model, where the presence of a thermal component results in a softening of α with time. On the other hand, the second emission episode is best fitted with just a Cp1 model. The spectral index is found to be consistent with slow-cooling synchrotron emission. The time-integrated polarisation measurement of each emission episode shows that the first episode is un- or weakly polarised (polarisation fraction $< 37\%$). During the second episode, however, a strong polarisation is detected with polarisation $> 43\%$. The flux lightcurve of the afterglow obtained by the XRT shows the presence of a flare and a jet break, the latter being supported also by the UVOT lightcurve. The jet opening angle is estimated to be $\sim 1.2^\circ$, and a low radiation efficiency of $\sim 11\%$ is found. Our analysis reveals that (i) a transition in the spectrum from a combination of thermal and non-thermal to a completely non-thermal emission, and (ii) a simultaneous change in polarisation from a lower to a higher degree. The energy flux lightcurve observed during the afterglow indicates that the jet is viewed on-axis by the observer. Based on this, a consistent physical picture is presented in this chapter. Using the composite modelling of the spectrum, polarisation and afterglow observations, it is inferred that the outflow is baryon dominated with mild magnetisation. The emission during the first episode is from the photosphere with sub-photospheric dissipation of the kinetic energy of the jet. These energetic electrons up-scatter the thermal radiation coming from regions close to the central engine. This



produces a quasi-thermal Comptonised spectrum, which gives rise to the observed non-thermal component. The second episode, on the other hand, is produced by synchrotron emission by electrons energised in the internal shocks occurring in the optically thin region beyond the photosphere, in the backdrop of ordered magnetic fields originating from the central engine.

Part II: Central Engine

The two types of possible central engines of GRBs are: (i) a hyper-accreting stellar-mass ‘black hole’, and (ii) a rapidly spinning and highly magnetised neutron star, called as ‘magnetar’. Several comprehensive studies have been done on the lightcurve properties of the early afterglows observed by *Swift*/XRT. The lightcurve features like late X-ray flares and plateau features indicate that central engine activities last longer than the duration of the prompt phase. The X-ray flares are perceived as the late time activity of the central engine. The observed X-ray plateau can be accounted for by the spin-down of magnetars, late time fallback of surrounding matter onto the black hole, or an external forward shock. But the X-ray plateau with a rapid drop at the end can possibly be explained by the magnetar model. Hence, the investigation of the observed lightcurve properties is useful for understanding the possible central engine.

In [Chapter 6](#), possible central engines in GRBs and their mechanisms for launching the relativistic jets are reviewed. The important discriminators like limits on the energetics, duration, etc., in the magnetar model, are presented in this chapter for ruling them out as central engine. For example, the maximum energy budget for a newly born millisecond magnetar is $\sim 10^{52}$ erg, which is estimated when the entire rotational energy gets converted into radiation. Hence, such constraints are useful for identifying the type of central engine.

In [Chapter 7](#), the upper limit on the energetics of the magnetar model is applied to rule them out as a central engine in some of the GRBs. To carry out this study, a sample of 135 *Fermi* detected GRBs is selected with known redshift information. The isotropic equivalent energy in γ -rays is computed using the bolometric fluence derived from *Fermi* data. Bursts with isotropic equivalent energy greater than 10^{52} erg are selected to form a sample of 105 hyper-energetic long GRBs. Due to the collimated nature of GRB jets, the beam-corrected energy, $E_{\gamma,beam}$ is the true energy of the burst to be used for further analysis. For this, the jet opening angles, θ_j are either adopted from the existing literature or estimated where required. Applying the condition $E_{\gamma,beam} > 10^{52}$ erg, we identify the central engines in 9 GRBs as black hole candidates. The estimated mass ranges up to $10 M_{\odot}$ for these black hole candidates, which are likely produced by the core-collapse of massive stars. The XRT lightcurves for these events show the presence of flares and multiple breaks. But, in none of the cases, plateau and steep decay are observed. In the black hole model, such X-ray flares can be explained by either fragmentation of the accretion disk into clumps at a large radius or by magnetic barriers also seen in magnetohydrodynamic simulations.

The observations of the Binary Neutron Star merger event GRB 170817A have confirmed some key aspects: (i) the presence of a relativistic jet, (ii) that the jet has some structure beyond the jet opening angle, and (iii) that the jet has been viewed off-axis. This indicates



that the observed prompt emission spectrum has a strong dependence on the viewing geometry of the jet. The **Band** function fits performed on the sGRBs spectrum reveals that for a significant number of bursts; (a) the low energy powerlaw indices are $\geq -2/3$, the line of death of synchrotron emission, and (b) the high energy powerlaw indices are found to be steep. These spectral features imply a narrow spectral shape and hence, suggest radiation from a non-dissipative photosphere.

In [Chapter 8](#), a sample of short GRBs is analysed using the spectral model of **multi-colour blackbody**, which is interpreted as the emission from a non-dissipative photosphere of a jetted outflow possessing an angle-dependent decreasing (powerlaw) Lorentz factor profile. About $\sim 67\%$ and $\sim 26\%$ of the sample are found to be consistent with **multi-colour blackbody** and a pure **blackbody** model, respectively. The opening angle (θ_j) of the GRB jet is also estimated using the traditional jet break that is observed in the afterglow. In cases where the jet break is not observed, the condition of jet confinement due to surrounding cocoon is used. The most probable value of θ_j is found to be $2^\circ \pm 1^\circ$, and median is estimated to be 6° . The powerlaw index of the low energy part of the mBB spectrum, along with the detection of a jet break in the afterglow, enables one to identify if the GRB is viewed within or outside the jet cone. Our interpretation of the sGRB spectra of the current sample within this spectral model shows that the probability of sGRBs observed within (or along the edge of) the jet cone is $\sim 56\%$ (18%). On further analysis of the outflow dynamics of the sGRBs observed on-axis, the average Lorentz factor (Γ) at the photosphere is found to be ~ 125 . The intrinsic luminosity of the sGRBs is found to lie in the range $10^{48} - 10^{53}$ erg/s. No correlation is observed between the mBB temperature and total isotropic energy of the bursts. The power law index of the decreasing Lorentz factor profile of the jet structure is found to be $1.4 - 2.3$. Several recent studies have shown that the physical model of synchrotron emission can produce reasonably good spectral fits to the GRB prompt emission spectra with even hard α values. However, we note that the synchrotron emission with hard α values can be obtained by: (a) a steep powerlaw electron energy distribution² (> 2.5), which may be physically unreasonable, and (b) a Maxwellian distribution, but it provides much wider spectra than the observed narrow spectra in our sample. In addition, the synchrotron self-absorption frequency can allow the slope to be as hard as the Rayleigh-Jeans index. But, it requires extremely high Lorentz factor of $\sim 10^4$ for observing the absorption frequency in the hard X-ray regime. Thus, it is difficult to explain the hard and narrow GRB spectra using synchrotron emission model. Our study finds that $\geq 92\%$ of the sample is consistent with the spectra expected from a non-dissipative photospheric emission of a structured jet. This suggests that the sGRB outflow is not Poynting-flux dominated, which in turn indicates that the central engine is unlikely to be a magnetar.

Gamma ray bursts, apart from being among the brightest explosions in the universe, are events that provide an avenue to explore several fields of astrophysics as well as other branches of physics. Despite several decades of extensive research in both observation and theory, the process of radiation giving rise to the observed gamma ray emission as well as the nature of the central engine powering these powerful events have still remained elusive. This thesis represents an attempt to resolve these mysteries by using an innovative approach of combining

²The common value of the powerlaw index of the energy distribution of relativistic electrons is $p \sim 2.2$.



both spectral and polarimetric information and associated physical modelling with all available constraints.

The thesis is based on the following papers:

1. Vidushi Sharma, Shabnam Iyyani, and Dipankar Bhattacharya, et al. ‘Time-varying polarised Gamma-Rays from GRB 160821A: Evidence for Ordered Magnetic Fields’, *ApJL* **882**,01, L10 (2019) [arXiv:1908.10885](#).
2. Vidushi Sharma, Shabnam Iyyani, and Dipankar Bhattacharya, et al., ‘Spectropolarimetric analysis of prompt emission of GRB 160325A: Jet with evolving environment of internal shocks’, *MNRAS* **493**, 01, 5218-5232 (2020) [arXiv:2003.02284](#).
3. Vidushi Sharma, Shabnam Iyyani, and Dipankar Bhattacharya, ‘Identifying black hole central engines in gamma-ray bursts’, *To be submitted*.
4. Shabnam Iyyani, and Vidushi Sharma, ‘Prompt emission of short gamma ray bursts: Clue to the view geometry and the post merger remnant’, *Submitted in ApJS*, [arXiv:2007.00020](#).



FACILITIES AT IUCAA

Computing Facility

The IUCAA Computing Facility continues to offer the state-of-the-art computing hardware and technology rich mobile work space for IUCAA members, associates and visitors. It also extends an array of specialized High Performance Computing (HPC) environments to the academic community for their research.

The hardware and devices currently managed by the computing facility include 340 servers and desktops, 90 laptops, 80 printers and scanners, three large HPC systems and over 7 Petabyte of storage, in addition to diverse equipments deployed for an extensive, high throughput wired and wireless campus-wide network. The number of registered WiFi devices is over 900, and e-mail accounts served by the computing facility amount to nearly 600.

IUCAA has its own registered domain name as “iucaa.in”. The WAN services are provided by the National Knowledge Network on a 1 Gbps fibre connectivity, with a fallback arrangement on a 50 Mbps line from Tata VSNL.

During the year emphasis was given to implementation of the following:

1) High Performance Computing Cluster (Pegasus) Storage Expansion

The demand for HPC cluster storage is increasing steadily. The storage of Perseus cluster was about 85% occupied within 18 months of its operation. Hence, to serve the computing requirement, we have expanded the storage attached to HPC Pegasus cluster by 1PB.

2) High Performance Computing Cluster (SARATHI) Storage Expansion

In the current year, 2PiB PFS storage with 30Gbps write and read (1:1) throughput has been added to the cluster from the LIGO - India funds. This will help to maintain most of the data from the LIGO - Virgo - KAGRA detector network at IUCAA.

3) High Performance Computing Cluster (Vroom) Storage Expansion

The MeerKAT Absorption Line Survey (MALS), led by IUCAA scientists, is one of the ten extensive surveys being carried out with the MeerKAT telescope in South Africa. The data are being transferred from South Africa to IUCAA through transportable media (tapes and disks) for processing at IUCAA by the MALS team. Currently, the MALS cluster was equipped with 1 PB usable storage. However, the data processing in last a few months has exhausted about 90% of the storage. Hence, in order to continue uninterrupted data processing, we have extended MALS storage by 1.5 PB.

4) Wired LAN Connectivity in Housing Colony

During the lockdown period, most of the faculty, students, and staff in the housing colony have been working from home. In order to facilitate this, we have enhanced the coverage of wired LAN



connectivity in the housing colony. In this project, we provided LAN connectivity to Type - 4D Quarters (Akashganga 14 - 25), Takshashila Flatlets (T13 -T 24), and Chittaranjan (C1 - C5).

5) UPS Battery Replacement

IUCAA has two independent data centres, both of which host very critical services. Power supply to these data centres is routed through UPS to provide uninterrupted services. For one of the data centres, we have a 280 KVA ABB UPS, whereas for the other, we have a 120 KVA Vertiv UPS. Batteries of these UPS were about four years old. Hence, we have replaced batteries of both the UPS systems.

6) All in One PCs for System Administrators

The existing all in one desktops used by the system administrator team were about 8 years old, and were out of warranty. It was very difficult to test latest version of software/packages on these systems. Hence, the replacement of old all in one desktops with new ones is in progress.

7) Facilitate Online Lectures

Due to pandemic situation, to conduct live lectures using zoom and Google classroom, a Video Conferencing System has been procured and installed. In addition, laptops have also been provided to the students to help to attend the lectures.

8) Implemented CCTV Surveillance

We have installed closed-circuit television cameras (CCTV) to enable surveillance on computer hardware, data centre NON-IT equipment, and for security. Currently, the Library open office, TV room (allocated for visitors), Computer Centre Corridor, New Data Centre Corridor and BMS terrace area are under CCTV surveillance

In order to facilitate work from home, to increase the WiFi coverage and to improve the stability of connectivity in IUCAA premises, we have installed ruckus R720 (7), ruckus H320 (10) indoor wireless access point, and ruckus T610 (7) outdoor wireless access point and also relocated existing access points for better coverage.

HP Laserjet Colour M775 printer (1), HP Laserjet 436 DN (2), HP Elite Desktop 800 G3 with Monitor (20), HP ProBook 440 G7 Laptop (10), HP ProBook 440 G6 Laptop (4), and MacBook Pro (4) were acquired for the academic community, visitors and administrative officers.

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 8 personnel, who carry out the daily functions that include:

1. Architecting overall IT solution/technologies required for IUCAA, and present it to Computer Users' Committee for their consensus.



2. Framing policy documents and finalizing them in consultation with the Computer Users' Committee members.
3. Drawing up specification of the RfP (Request for Proposal) tender document for IUCAA IT required to be purchased, and oversee all purchases related procedure and follow up.
4. Maintenance of IT hardware in 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, etc.
10. Day to day administration of VMware 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 centre 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 Big Data, AstroSat, LIGO, MALS, SUIT, etc.
16. Procurement, installation and periodic upgradation of mathematical software such as Matlab, IDL, Mathematica meant for general IUCAA users and cluster users.
17. Hardware maintenance and general system administration of clusters in IUCAA in coordination with OEM.
18. Assisting Estate Department with Data Centre management activities.
19. 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 requirement of the astronomy community associated with IUCAA. It has 60 compute nodes, each with 32 cores and 384 GB RAM. It uses infiniband EDR (100Gbps) as an inter-connect, 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 is attached to a 2 PB parallel file system (Lustre), which is capable of delivering 15GBps throughput. Theoretical computing speed of the Pegasus Cluster is 100 TF. The Pegasus cluster has been utilized by about 50 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 LIGO Scientific Collaboration (LSC), which includes many IUCAA members and associates. The cluster is comprised of heterogeneous compute servers, 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 TF. 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 16 compute nodes (DELL), which delivers 25 TF computing speed and has a parallel file system (DDN) of 2.5 PB usable capacity attached to it.

HPC Clusters Listed in Top Supercomputers in India

Sarathi Cluster Phase III, Pegasus Cluster, and Sarathi Cluster Phase II are listed at 22nd, 32nd and 35th rank respectively in the list of top Supercomputers in India published on January 31, 2021. The list is maintained and supported by CDAC's Terascale Supercomputing Facility (CTSF), CDAC, Bengaluru.

The list is available at
<http://topsc.cdacb.in/jsps/jan2021/index.html>



*Subset of the Staff of the Computing Facility at IUCAA Data Centre, with the Head of Computing Facility.
(The High Performance Computing clusters are seen in the background)*



IUCAA High Performance Computing clusters, Perseus, Pegasus and Sarathi



Chiller plant assembly for IUCAA Data Centre



*Power conditioning room for IUCAA Data Centre with UPS, battery banks and control panels
(All Pictures are Credited to Shashank Tarphe, IUCAA)*



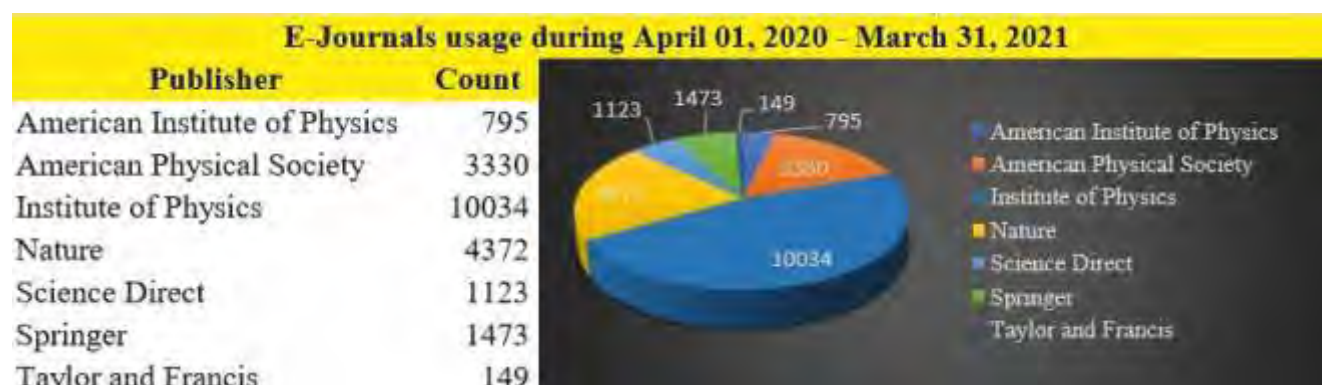
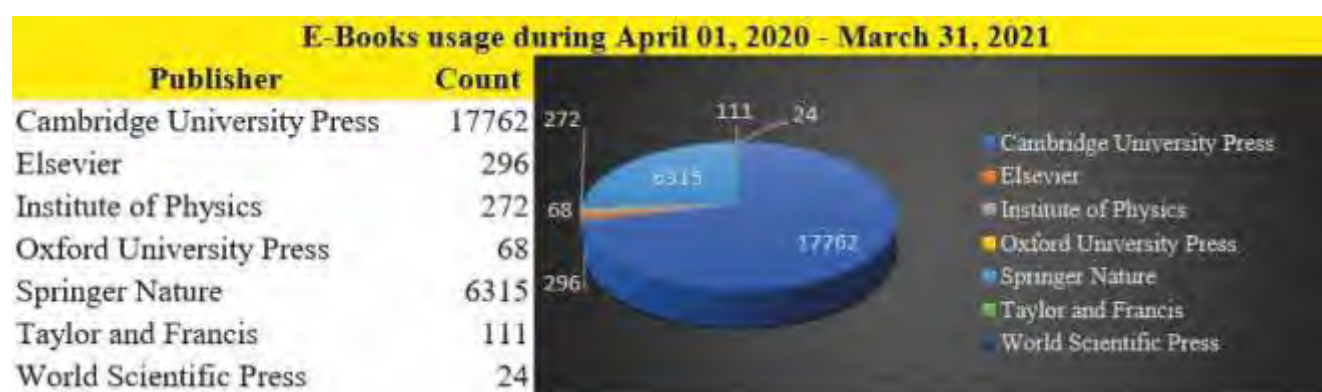
LIBRARY

The IUCAA library provides access to a comprehensive collection of books and journals in astronomy, astrophysics, and related areas. The library added Springer Physics and Astronomy E-Books collection for 2020 - 2021, comprising 388 e-books, and renewed its subscription to the Grammarly Premium, and the Overleaf Premium software. Further, the library renewed its subscription to 79 journals for the year.

In addition to the e-journal subscriptions, the library continued to receive access to the following seven e-resources courtesy, E-Shodh Sindhu Consortium for Higher Education Electronic Resources, MHRD, Government of India.

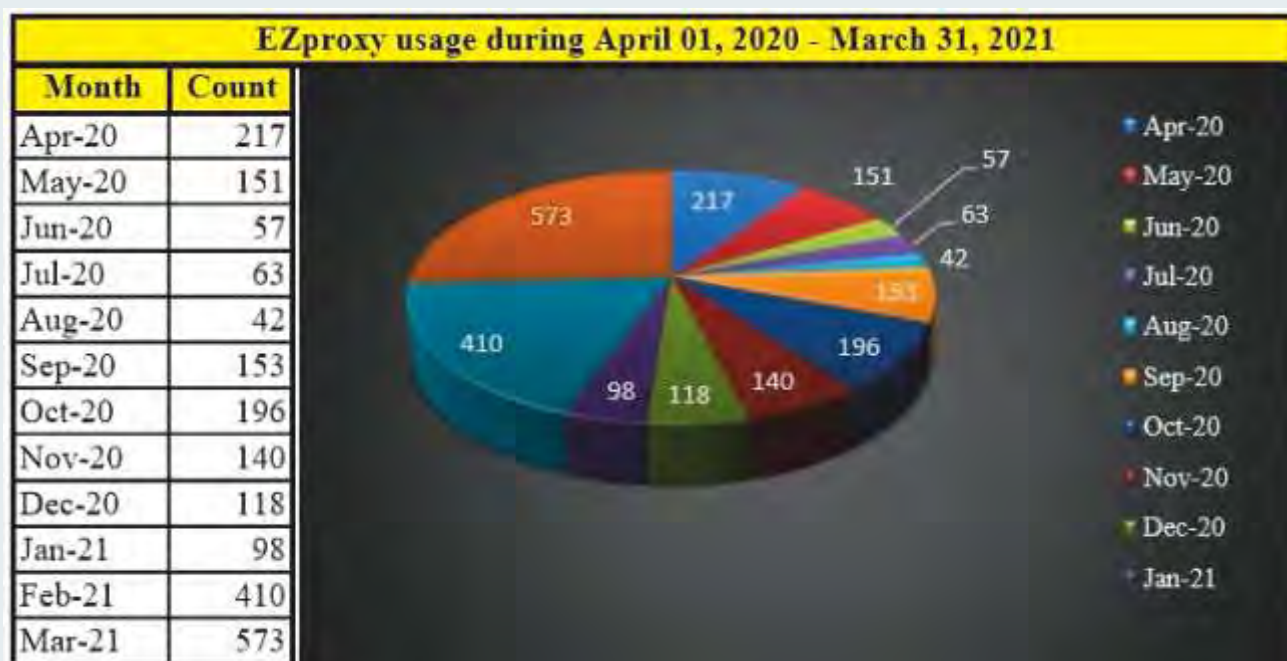
- American Institute of Physics
- American Physical Society
- Institute for Studies in Industrial Development (ISID) database.
- JGate Plus
- Springer Link and Nature
- Taylor and Francis
- Web of Science.

The E-Books and E-Journals usage during the year is depicted below:



The EZproxy access and authentication software has been deployed by the library to facilitate off-campus access to all the e-resources subscribed by the library. The following e-resources have been accessed by users including Visiting Associates of IUCAA using EZproxy.

- American Association of Physics Teachers
- American Institute of Physics
- American Physical Society
- American Scientist
- Annual Review of Astronomy and Astrophysics
- Applied Optics
- Cambridge University Press
- EDP Sciences
- Institute of Physics
- IUCAA Institutional Repository
- Nature
- New Scientist
- Physics Today
- Physics Education
- Popular Science
- Science Direct
- Springer Nature
- Taylor and Francis
- Web of Science
- World Scientific



In addition to the usual library business, the library team of five professionals and one library trainee facilitated the following activities and services:

1. Document Delivery Service for articles – Fulfilled 251 article requests from 131 users.
2. The library processed 15 publications charge requests.
3. The library provided plagiarism reports using Urkund for research papers.
4. The library YouTube Channel has a collection of 206 videos. The current subscriber base is 5,452, and there have been a total of 96,317 views.
5. The library staff assisted the Publications Department in compiling the list of publications by IUCAA Academics, and the Visiting Associates for the 2020-21 Annual Report.

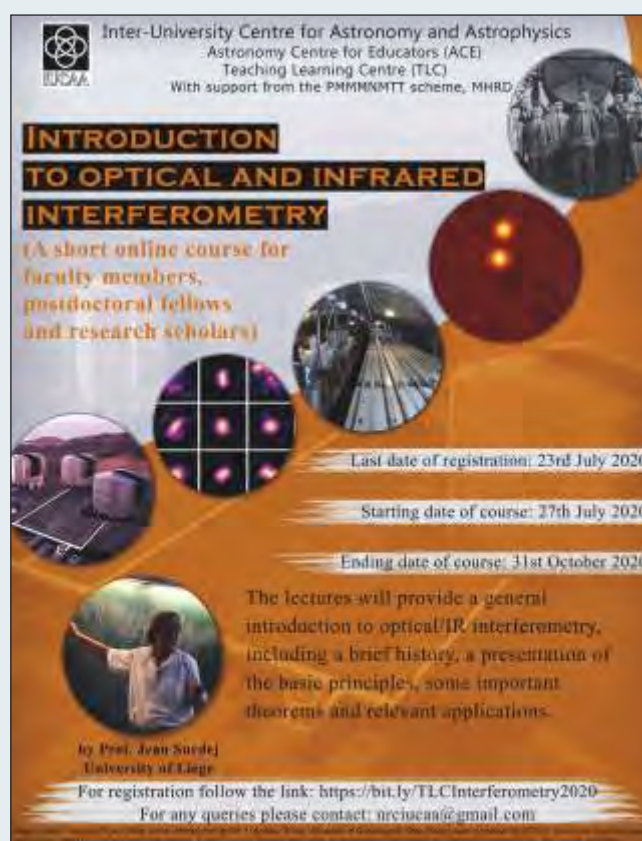
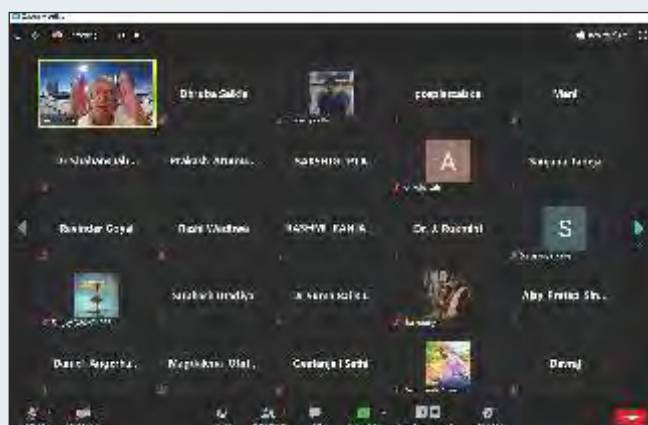


ACE-RPL- ACTIVITIES

An Introduction to Optical and Infrared Interferometry

An online course titled An Introduction to Optical and Infrared Interferometry, was organized by the Teaching Learning Centre of the Astronomy Centre for Educators, IUCAA, from the end of July 2020 till the end of September 2020 with Jean Surdej (Honorary Director, Extragalactic Astrophysics and Space Observatories Group, University of Liege, Belgium) as the instructor. Avinash Deshpande (IUCAA) also gave a set of four lectures on Fourier Transforms. These interactions were also via Zoom, while the Learning Management System Moodle was set up where all video presentations, quizzes, assignments, etc. were available. Over a hundred participants consisting largely of college and university faculty

members from India, as well as a few from outside the country were registered for the course. This course was coordinated by Prakash Arumugasamy (IUCAA).



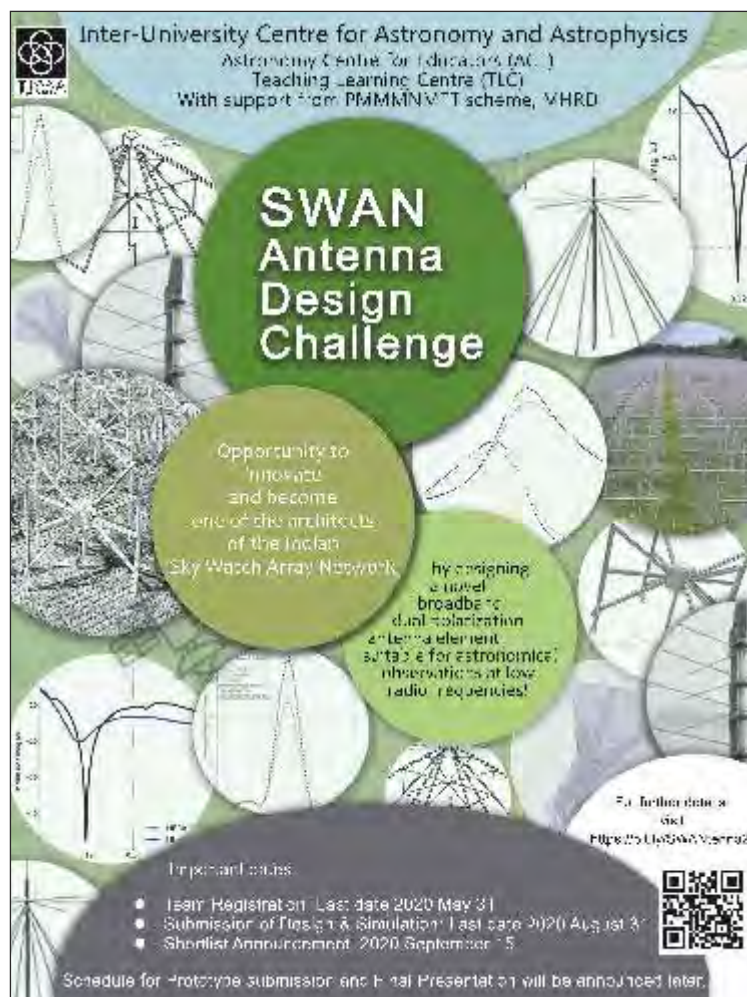
Antenna Design Competition: SWANtenna– 2020

During the time of this pandemic, efforts were also being made by the Teaching Learning Centre of the Astronomy Centre for Educators, IUCAA, to either design and later build, or do experiments with equipment and/or software, which the participants have access to or may be available at their homes. One such initiative was the design of a low-frequency antenna for radio astronomical observations as part of the Sky Watch Array Network (SWAN), which started at the Raman Research Institute, Bengaluru, by Avinash Deshpande (IUCAA). This competition titled SWANtenna – 2020, was announced in May 2020, and was open to teams of faculty members and students from across the country, with the possibility of teams being across institutions to promote inter-institutional collaboration. In an overwhelming response, over 35 teams, involving about 70 faculty members, who were mentors, and over 300 students, from across the country registered and worked during the four months, from June to September 2020, towards designing an antenna element with the desired specifications. WIPL-D, a Serbian firm specializing in EM simulation and software in the field of electromagnetism, generously provided free access to one of their



software packages for all participants. Entries from 18 teams consisting of more than 150 participants reporting details of their completed antenna design and assessment of performance characteristics from simulations, have been received by the extended deadline of September 30, 2020.

These are now being judged by a jury of leading antenna experts of the country, headed by Raghunath Shevgaonkar (Former Director, IIT, Delhi, and presently Vice-Chancellor, Bennett University), Subramaniam Ananthakrishnan (Former Dean, NCRA-TIFR, Pune, and presently at the Savitribai Phule Pune University), Ajit T. Kalghatgi (Former Director, R&D, BEL), Shiban Koul (Emeritus Professor, Centre for Applied Research in Electronics, IIT, Delhi), Surendra Pal (Professor Satish Dhawan Professor and Senior Adviser, Satellite Navigation Centre, ISRO), and K. P. Ray (Dean, DIAT). A set of promising designs will be short-listed for proto-type fabrication and tests. The SWANtenna competition was being coordinated by Avinash Deshpande, and other colleagues at TLC.



Radio Astronomy Winter School

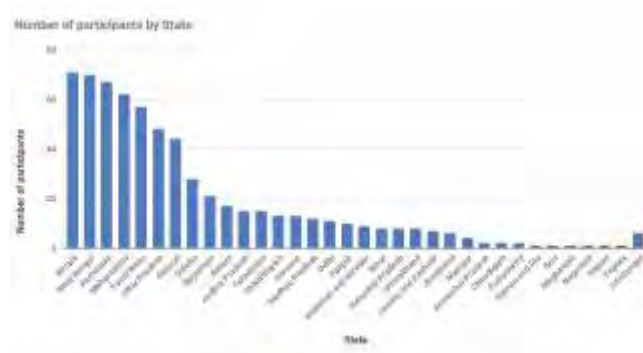
The thirteenth Radio Astronomy Winter School (RAWS – 2020) was organized online jointly by IUCAA and NCRA-TIFR, during December 28, 2020 – January 9, 2021. There were well over 600 applicants, of which 50 were selected to participate via Zoom, and the rest could listen via YouTube. In addition to the presentations and tutorials and discussion sessions on various topics related to radio astronomy, sometimes went on till late in the night, there were also carefully designed experiments, which the participants conducted in their homes. The experiments were done in 10 teams of 5 members each, including a teacher mentor in each team from different universities and colleges in the country. These experiments included a few which used mobile phones and laptops as transmitters and receivers of radio waves. The participants examined the variation of the signal with distance and effects of attenuation along its path. They also explored the effects of using plane and corner reflectors on the received radio signals. They did an interesting experiment on the interference of radio signals received directly and also bouncing off a metal/aluminium reflector. This mimicked the early sea-cliff radio interferometer made during the 1940s in Australia. In addition, there were work sheets on radiometer



basics and experiments involving analysis of data obtained from both the Ooty Radio Telescope, and the Giant Metrewave Radio Telescope. Although, having a school with participants in the same physical space has its benefits, the online format opened up possibilities of a participant from Brazil presenting work done by her team in India, and one from Bangladesh, all working together and interacting via the web. The teacher mentors worked very closely with the student participants. In addition to the presentations by the teams on the experiments they had done, a discussion on career opportunities in astronomy and astrophysics, and a quiz among the different teams were held during the last two days. Eighteen resource persons from both IUCAA and NCRA-TIFR took part in the school. The core organizing group consisted of Ashish Mhaske, Avinash Deshpande, Dhruba J. Saikia, Jameer Manur, and Prakash Arumugasamy (all from IUCAA), and Ruta Kale and Subhashis Roy (both from NCRA-TIFR).

Annual Refresher Programme in Teaching: ARPIT – 2020

A course on Stars and Stellar Systems, consisting of 36 video presentations separated into 10 modules on varied aspects of stars and stellar evolution was made by NRC of IUCAA for ARPIT - 2019. The modules are on Stars and Stellar Evolution by Sarita Vig (IIST, Thiruvananthapuram), Stellar Variability by Sukanta Deb (Cotton University, Guwahati), Stars and Cosmology by Sivarani Thirupathi (IIA, Bengaluru), Star Clusters and Star Formation by Ram Sagar (IIA, Bengaluru), and Manoj Puravankara (TIFR, Mumbai), Compact Stars by Dipankar Bhattacharya (IUCAA), Astrophysics of Neutron Stars by Sushan Konar (IUCAA), Binary Stellar Systems by Sudip Bhattacharyya (TIFR, Mumbai), The Sun by Dibyendu Nandi (IISER, Kolkata), Durgesh Tripathi (IUCAA), and Divya Oberoi (NCRA-TIFR), Helio- and Astero-Seismology by Shravan Hanasoge (TIFR, Mumbai), and Extrasolar Planets by Anwesh Majumdar (HBCSE, TIFR, Mumbai). In 2020, this course has been offered





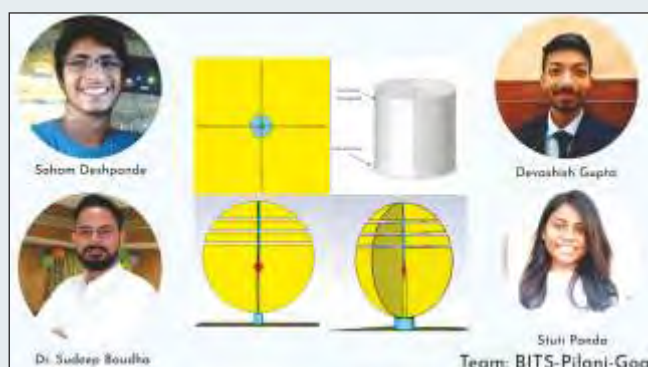
again due to the pandemic situation. A total of 732 participants have registered for the course before the deadline of December 31, 2019, of which about half are faculty members in colleges and universities. The registered participants are from almost all parts of the country and a few from abroad. The figures show the resource persons and the state-wise distribution of the participants. The course has been coordinated by Dhruba J. Saikia (IUCAA).

Results of SWANtenna – 2020 Competition

Of the eighteen teams across the country, which had submitted their entries by the deadline of September 30, 2020 to design an antenna element for the Sky Watch Array Network as reported in the October 2020 issue of Khagol, five teams were invited to give presentations based on detailed assessment by a jury panel of eminent



antenna experts of the country. The jury headed by Raghunath Shevgaonkar (Former Director, IIT, Delhi, and presently Vice-Chancellor, Bennett University), consisted of Subramanian Ananthakrishnan (Former Dean, NCRA-TIFR, Pune, and presently at the Savitribai Phule Pune University), Ajit T. Kalghatgi (Former Director, R&D, BEL), ShibanKoul (Emeritus Professor, Centre for Applied Research in Electronics, IIT, Delhi), Surendra Pal (Satish Dhawan Professor and Senior Adviser, Satellite Navigation Centre, ISRO), and K. P. Ray (Dean, DIAT). They recommended three teams, whose antenna element design could be prototyped. These three teams, shown here along with the antenna elements they designed are from BITS-Pilani, Goa; Fergusson College(Autonomous), Pune; and Thapar Institute of Engineering and Technology, Patiala. The SWANtenna-2020 competition was coordinated by the Astronomy Centre for Educators.





Advanced Course on Pulsar Astrophysics



An online Advanced Course on Pulsar Astrophysics for faculty members, post-doctoral fellows and research scholars working in the field, was held during January 25 – April 10, 2021. A set of 20 lectures by Dipankar Bhattacharya (IUCAA) took a broad and intensive look at the results of pulsar astrophysics. It covered pulsar magnetosphere modelling, radio and high-energy radiation from pulsars, neutron star interiors, and the equation of state. In addition to listening to the pre-recorded videos, there were regular interactions with Dipankar Bhattacharya. Assignments were given regularly and quizzes held. There were about 50 participants from various institutions across the country. The course was coordinated by Prakash Arumugasamy (IUCAA).



Introductory Course on Astronomy and Astrophysics

An online Introductory Course on Astronomy and Astrophysics for college teachers with some emphasis on teachers from the north-east was conducted jointly by the Teaching Learning Centre of IUCAA and the IUCAA Centre for Astronomy Research and Development (ICARD) of Tezpur University. It was held during January 27 – April 8, 2021. The course took on board the syllabuses on astronomy and astrophysics,



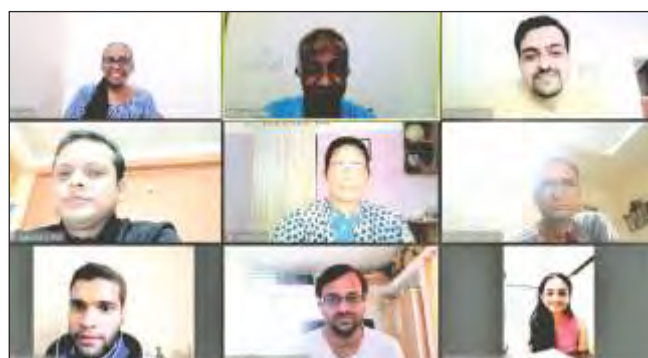
which have been introduced recently at the undergraduate level at Gauhati University and Assam University, and highlighted the recent developments in the field along with the basic required pedagogy. The topics covered included multi-messenger astronomy, stars and stellar evolution, galaxies and clusters of galaxies, and astronomical techniques. The resource persons were: Biman Nath (Raman Research Institute, Bengaluru), Biman Medhi (Gauhati University,



Guwahati), and Somak Raychaudhury and Dhruba J. Saikia (both from IUCAA). The participants were introduced to stellarium, an open source planetarium for the computer, to explore the night sky, and a tutorial conducted on it by Prakash Arumugasamy (IUCAA). Two online quizzes were held as part of the course. There were about 40 participants from all over the country including several from the north-east. The course was coordinated by Gazi Ahmed and Rupjyoti Gogoi (both from Tezpur University) and Dhruba J. Saikia.

Interactions with ARPIT 2020 Participants

An interaction session of the ARPIT 2020 participants with the resource persons was scheduled on each Sunday of March 2021 to ask questions, and discuss any material covered in the ARPIT course titled Stars and Stellar Systems. The participants of the Introductory Astronomy and Astrophysics course were also invited to participate. These sessions produced interesting discussions on many of the topics covered in the course, and helped clear possible doubts. The images show two different sessions in progress.





Workshop on Astronomy and Astrophysics



A Workshop on Astronomy and Astrophysics was organized at Srikishan Sarda College, Hailakandi, Assam, during January 22 - 28, 2020, in response to the new syllabus being introduced at the undergraduate level by the Assam University. The workshop was coordinated by Rupam Sen (Srikishan Sarda College), and D. J. Saikia.

(For details, see Khagol, No. 123, July 2020)



Session on Teaching in Astronomy and Astrophysics



A vibrant and informative session on Teaching in Astronomy and Astrophysics, sharing experiences, and discussing on how to take this further, was held on February 14, 2020 at IISER - Tirupati, on the occasion of the 38th meeting of the Astronomical Society of India.

(For details, see Khagol, No. 123, July 2020)

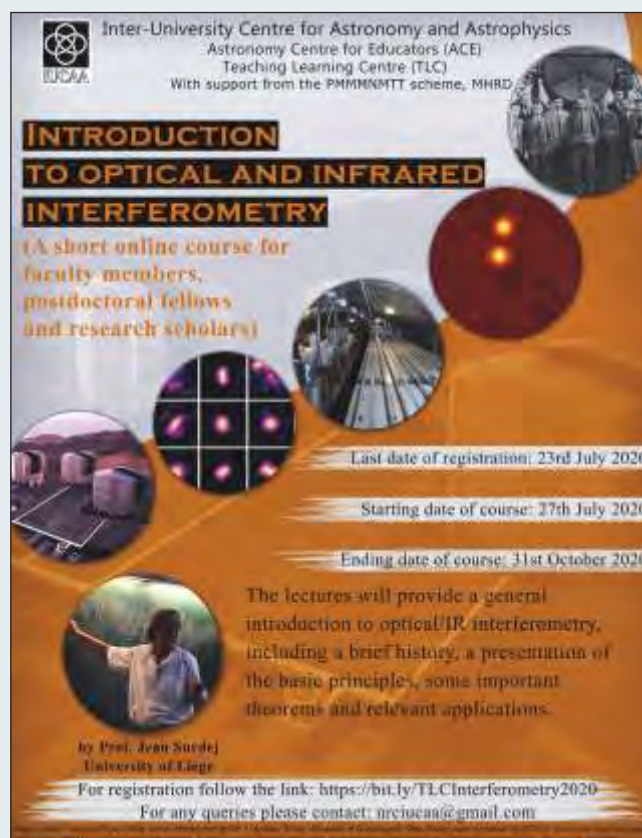
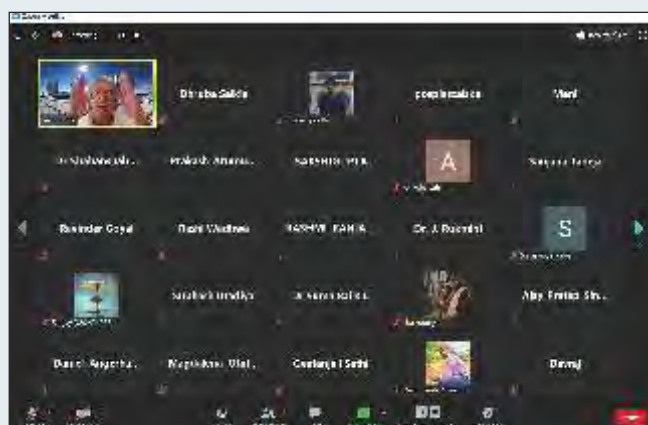




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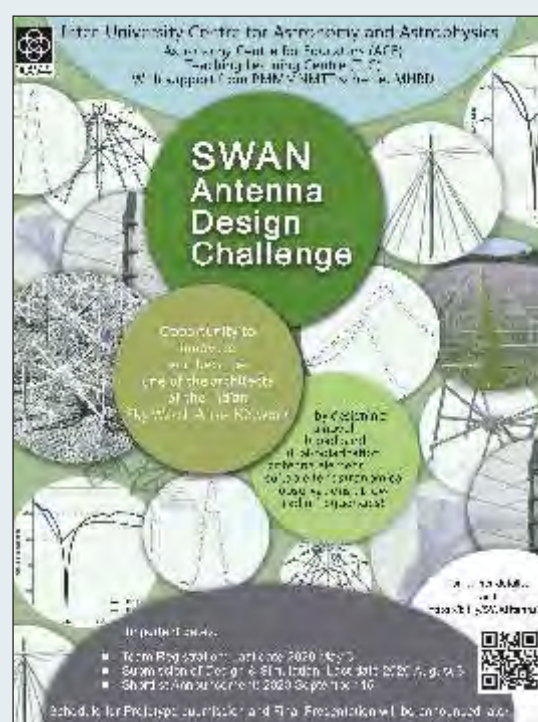
(For details, see Khagol, No. 124, October 2020)



Antenna Design Competition: SWANtenna– 2020

During the time of this pandemic, efforts were also being made by the Teaching Learning Centre of the Astronomy Centre for Educators, IUCAA, to either design and later build, or do experiments with equipment and/or software, which the participants have access to or may be available at their homes. One such initiative was the design of a low-frequency antenna for radio astronomical observations as part of the Sky Watch Array Network (SWAN), which started at the Raman Research Institute, Bengaluru, by Avinash Deshpande (IUCAA). This competition titled SWANtenna – 2020, was announced in May 2020. The SWANtenna competition was being coordinated by Avinash Deshpande, and other colleagues at TLC.

(For details, see Khagol, No. 124, October 2020)

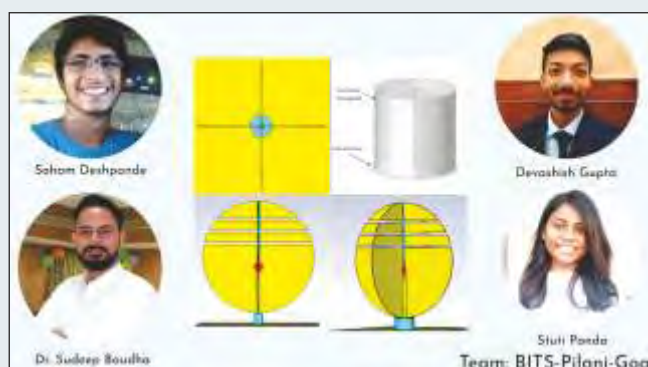




Results of SWANtenna – 2020 Competition

Of the eighteen teams across the country, which had submitted their entries by the deadline of September 30, 2020 to design an antenna element for the Sky Watch Array Network as reported in the October 2020 issue of Khagol, five teams were invited to give presentations based on detailed assessment by a jury panel of eminent antenna experts of the country. The SWANtenna-2020 competition was coordinated by the Astronomy Centre for Educators.

(For details, see Khagol, No. 125, January 2021)





Introductory Course on Astronomy and Astrophysics

An online Introductory Course on Astronomy and Astrophysics for college teachers with some emphasis on teachers from the north-east was conducted jointly by the Teaching Learning Centre of IUCAA and the IUCAA Centre for Astronomy Research and Development (ICARD) of Tezpur University. It was held during January 27 – April 8, 2021. The course was coordinated by Gazi Ahmed and Rupjyoti Gogoi (both from Tezpur University) and Dhruba J. Saikia.

(For details, see Khagol, No. 126, April 2021)





RESEARCH BY VISITING ASSOCIATES

RESEARCH BY VISITING ASSOCIATES

Sheelu Abraham

A machine learning approach for GRB detection in AstroSat CZTI data

We present a machine learning (ML) based method for automated detection of Gamma-Ray Burst (GRB) candidate events in the range 60 keV - 250 keV from the *AstroSat* Cadmium Zinc Telluride Imager data. We use density-based spatial clustering to detect excess power and carry out an unsupervised hierarchical clustering across all such events to identify the different light curves present in the data. This representation helps to understand the instrument's sensitivity to the various GRB populations and identify the major non-astrophysical noise artefacts present in the data. We use Dynamic Time Warping (DTW) to carry out template matching, which ensures the morphological similarity of the detected events with known typical GRB light curves. DTW alleviates the need for a dense template repository often required in matched filtering like searches. The use of a similarity metric facilitates outlier detection suitable for capturing previously unmodelled events. We briefly discuss the characteristics of 35 long GRB candidates detected using the pipeline and show that with minor modifications such as adaptive binning, the method is also sensitive to short GRB events. Augmenting the existing data analysis pipeline with such ML capabilities alleviates the need for extensive manual inspection, enabling quicker response to alerts received from other observatories such as the gravitational-wave detectors. This work has been done in collaboration with Nikhil Mukund, Ajay M. Vibhute, Vidushi Sharma, Shabnam Iyyani, et al.

Gouri Ambika

Early warning signals indicate a critical transition in Betelgeuse

Critical transitions occur in complex dynamical systems when the system dynamics undergoes a regime shift. These can often occur with a little change in the mean amplitude of the system response prior to the actual time of transition. The recent dimming and brightening event in

Betelgeuse occurred as a sudden shift in the brightness and has been the subject of much debate. Internal changes or an external dust cloud have been suggested as reasons for this change in variability. We examine whether the dimming and brightening event of 2019-20 could be due to a critical transition in the pulsation dynamics of Betelgeuse by studying the characteristics of the light curve prior to transition. We calculated the quantifiers hypothesized to rise prior to a critical transition for the light curve up to the dimming event. These included the auto-correlation at lag-1, variance, and the spectral coefficient calculated from detrended fluctuation analysis, in addition to two measures that quantify the recurrence properties of the light curve. Significant rises are confirmed using the Mann-Kendall trend test. We see a significant increase in all quantifiers ($p < 0.05$) prior to the dimming event. This suggests that the event was a critical transition related to the underlying nonlinear dynamics of the star. Together with results that suggest a minimal change in Te and IR flux, a critical transition in the pulsation dynamics might be a reason for the unprecedented dimming of Betelgeuse. The rise in the quantifiers we studied prior to the dimming event supports this possibility. This work has been in collaboration with Sandip V. George, Sneha Kachhara, and Ranjeev Misra.

Multiplex recurrence networks from multi-lead ECG data

We present an integrated approach to analyze the multi-lead electrocardiogram (ECG) data using the framework of multiplex recurrence networks (MRNs). We explore how their intralayer and interlayer topological features can capture the subtle variations in the recurrence patterns of the underlying spatio-temporal dynamics of the cardiac system. We find that MRNs from ECG data of healthy cases are significantly more coherent with high mutual information and less divergence between respective degree distributions. In cases of diseases, significant differences in specific measures of similarity between layers are seen. The coherence is affected most in the cases of diseases associated with localized abnormality such as bundle branch block. We note that it is important to do a comprehensive analysis using all the measures to arrive at disease-specific patterns. Our approach is very general and as such can be



applied in any other domain where multivariate or multi-channel data are available from highly complex systems. This work has been done in collaboration with Sneha Kachhara .

Bijan K. Bagchi

Ermakov-Pinney equation for time-varying mass systems

We extend Fring-Tenney approach of constructing invariants of constant mass time-dependent systems to the case of a time-dependent mass particle. From a coupled set of equations described in terms of guiding parameter functions, we track down a modified Ermakov-Pinney equation involving a time-dependent mass function. As a concrete example, we focus on an exponential choice of the mass function. This work has been done in collaboration with Achal Vinod.

Qualitative analysis of a classical double oscillator model

A classical double oscillator model, that includes in certain parameter limits, the standard harmonic oscillator and the inverse oscillator, is interpreted as a dynamical system. We study its essential features and make a qualitative analysis of orbits around the equilibrium points, period-doubling bifurcation, time series curves, surfaces of section and Poincare maps. An interesting outcome of our findings is the emergence of chaotic behaviour when the system is confronted with a periodic force term like $f \cos \omega t$. This work has been done in collaboration with Dibyendu Ghosh, and Lal M. Saha.

Tanwi Bandyopadhyay

Bouncing cosmology for entropy corrected models in Hořava-Lifshitz gravity and fractal universe

The modified field equations are written in logarithmic and power law versions of entropy corrected models in Einstein's gravity in the background of FRW universe. In one section, a brief review of the Hořava-Lifshitz gravity is discussed and the modified field equations in logarithmic and power law versions of entropy corrected models in Hořava-Lifshitz gravity are formulated. The stability analysis for these models are performed by describing the dynamical

system. In another section, a brief review of the fractal universe is presented and the modified field equations in logarithmic and power law versions of entropy corrected models in fractal universe are formulated. The stability analysis for the dynamical system for these models in the framework of fractal universe are described. Furthermore, the bouncing scenarios of the universe in Hořava-Lifshitz gravity and fractal model for both logarithmic and power law entropy corrected versions in $k = 0, +1, -1$ separately are analyzed. For different cases, the validity of null energy condition (NEC) at the time of bounce is examined and the behaviours of the physical quantities are depicted through diagrams. Finally, the modifications in Newton's law of gravitation is discussed for the chosen models. This work has been done in collaboration with Ujjal Debnath.

Arunima Banerjee

Determination of the relative inclination and the viewing angle of an interacting pair of galaxies using convolutional neural networks

Constructing dynamical models for interacting galaxies constrained by their observed structure and kinematics crucially depends on the correct choice of the values of their relative inclination (i), and viewing angle (θ) (the angle between the line of sight and the normal to the plane of their orbital motion). We construct Deep Convolutional Neural Network (DCNN) models to determine the i and θ of interacting galaxy pairs, using N-body + Smoothed Particle Hydrodynamics (SPH) simulation data from the GALMER database for training. GalMer simulates only a discrete set of i values ($0^\circ, 45^\circ, 75^\circ$ and 90°) and almost all possible values of θ values in the range, $[-90^\circ, 90^\circ]$. Therefore, we have used classification for i parameter and regression for θ . In order to classify galaxy pairs based on their i values only, we first construct DCNN models for (i) 2-class ($i = 0^\circ, 45^\circ$) (ii) 3-class ($i = 0^\circ, 45^\circ, 90^\circ$) classification, obtaining F_1 scores of 99% and 98% respectively. Further, for a classification based on both i and θ values, we develop a DCNN model for a 9-class classification using different possible combinations of i and θ , and the F_1 score is 97%. To estimate θ alone, we have used regression, and obtained a mean squared error value of 0.12. Finally, we also tested our DCNN model on real data from



Sloan Digital Sky Survey. Our DCNN models could be extended to determine additional dynamical parameters, currently determined by trial and error method. This work has been done in collaboration with Prem Prakash, and Pavan K. Perepu.

Dynamical modelling of disc vertical structure in superthin galaxy ‘UGC 7321’ in braneworld gravity: An MCMC study

Low surface brightness (LSBs) superthins constitute classic examples of very late-type galaxies, with their disc dynamics strongly regulated by their dark matter halos. We consider a gravitational origin of dark matter in the brane world scenario, where the higher dimensional Weyl stress term projected onto the 3-brane acts as the source of dark matter. In the context of the braneworld model, this dark matter is referred to as the ‘dark mass’. This model has been successful in reproducing the rotation curves of several low surface brightness and high surface brightness galaxies. Therefore, it is interesting to study the prospect of this model in explaining the vertical structure of galaxies which has not been explored in the literature so far. Using our 2-component model of gravitationally-coupled stars and gas in the external force field of this dark mass, we fit the observed scale heights of stellar and atomic hydrogen (HI) gas of superthin galaxy ‘UGC7321’ using the Markov Chain Monte Carlo approach. We find that the observed scale heights of ‘UGC7321’ can be successfully modelled in the context of the braneworld scenario. In addition, the model predicted rotation curve, also matches the observed one. The implications on the model parameters are discussed. This work has been done in collaboration with Aditya Komanduri, Indrani Banerjee, and Soumitra Sengupta.

Sarmistha Banik

New equation of state involving Bose-Einstein condensate of antikaon for supernova and neutron star merger simulations

We have studied an X-ray transient source, 4U 1901+03 which has been classified as a Be-X-ray binary based on its X-ray timing properties. We compute a new equation of state table including Bose-Einstein condensate of K^- mesons for core collapse supernova and neutron star merger simulations. Nuclei and interacting nucleons in

non-uniform matter is described in an extended version of the nuclear statistical equilibrium model including excluded volume effects, whereas the uniform matter at higher densities is treated in the relativistic hadron field theory with density dependent couplings. The equation of state table is generated for a wide range of density (10^{-12} to $\sim 1 \text{ fm}^{-3}$), positive charge fraction (0.01 to 0.60) and temperature (0.1 to 158.48 MeV). The impact of antikaon condensate is investigated on different thermodynamic quantities, for example, free energy per baryon, entropy per baryon, pressure as well as compositions of matter. Furthermore, critical temperatures of antikaon condensation and the phase diagram of matter are also studied. This work has been done in collaboration with Tuhin Malik, and Debades Bandyopadhyay.

Prasad Basu

An improved approach to find the height of the accretion disk

We propose an improved approach to find the height of the accretion disks around Kerr black holes. The vertical structure of the disk is obtained using a relativistic continuity equation and finally, the result is expressed in terms of the accretion rate and flow parameters. For different models of thin and slim disks, the expressions of the vertical height of the accretion disk are also been reviewed chronologically. We further discuss the basic assumptions, merits, and demerits of these models. Compared to existing approaches, our analysis is more self-consistent and less axiomatic. Further, we find that disk height is directly proportional to accretion rate, which could be important to find out the vertical structure of the accretion disk in different black hole accretion states in a hysteresis cycle. This work has been done in collaboration with Sangita Chatterjee, and Soumen Mondal.

Aru Beri

Evolution of timing and spectral characteristics of 4U 1901+03 during its 2019 outburst using the Swift and NuSTAR observatories

In 2019, the X-ray transient source 4U 1901+03 underwent a very bright (with peak X-ray flux of $\sim 8 \times 10^{-9} \text{ erg cm}^{-2} \text{ s}^{-1}$) and long (duration of 6 months) Type-II outburst. During this outburst, several multi-wavelength observations



were performed as part of Simultaneous Multiwavelength Astronomy Research in Transients NETwork (SmartNet) and 4U 1901+03 was observed four times with Nuclear Spectroscopic Telescope Array (NuSTAR), and several Swift observations were made. In our work, we have used Swift and NuSTAR observations. We performed broadband spectroscopy in the 1-70 keV energy band using four observations made with Swift and NuSTAR at different intensity levels. Our timing results reveal the presence of highly variable pulse profiles dependent on both luminosity and energy. Our spectroscopy results showed the presence of CRSF at 30 keV, which is highly luminosity and pulse-phase dependent. Phase-averaged spectra during the last two observations, made close to the declining phase of the outburst showed the presence of this feature at around 30 keV. We also found that 30 keV feature was significantly detected in the pulse-phase resolved spectra of observations made at relatively high luminosities. Non-detection of CRSF at certain pulse phases is explained as a result of large gradient of the magnetic field strength over the visible column height or latitudes on the stellar surface. Moreover, all spectral fit parameters showed a strong pulse phase dependence. In line with the previous findings, an absorption feature at around 10 keV is significantly observed in the phase-averaged X-ray spectra of all observations and also showed a strong pulse phase dependence. This work has been done in collaboration with Tinku Girdhar, Nirmal K. Iyer, and Chandreyee Maitra.

AstroSat observations of the first galactic ULX pulsar Swift J0243.6+6124

Ultra-luminous X-ray sources (ULXs) are non-nuclear point-like objects with apparent luminosities exceeding 10^{39} erg s⁻¹. Coherent X-ray pulsations were discovered from a ULX in M82, thanks to the fast timing capability of NuSTAR, making it the first ULX pulsar (ULP). Currently, only a handful of ULPs are known. Swift J0243.6+6124 is the first Galactic ULP, and was observed with *AstroSat* during its 2017-2018 outburst at both sub- and super-Eddington levels of accretion with X-ray luminosities of $L_X \sim 7 \times 10^{37}$ and 6×10^{38} erg s⁻¹, respectively. Our broadband timing and spectral observations show that X-ray pulsations at ~ 9.85 s

have been detected up to 150 keV when the source was accreting at the super-Eddington level. The pulse profiles are a strong function of both energy and source luminosity, showing a double-peaked profile with pulse fraction increasing from $\sim 10\%$ at 1.65 keV to 40–80 % at 70 keV. The continuum X-ray spectra are well-modeled with a high energy cut-off power law ($\gamma \sim 0.6 - 0.7$) and one or two blackbody components with temperatures of ~ 0.35 keV and 1.2 keV, depending on the accretion level. No iron line emission is observed at sub-Eddington level, while a broad emission feature at around 6.9 keV is observed at the super-Eddington level, along with a blackbody radius (121–142 km) that indicates the presence of optically thick outflows. This work has been done in collaboration with Sachindra Naik, Kulider P. Singh, Dipankar Bhattacharyya, Gulab C Dewangan, et al.

Piyali Bhar

Study on anisotropic stars in the framework of Rastall gravity

We investigate the existence of high dense compact objects in the light of Rastall gravity theory. The material content is driven by an imperfect fluid distribution and the inner geometry is described by the Tolman-Kuchowicz spacetime. The validity of the obtained model is checked by studying the main salient features, such as energy, density, radial and tangential pressures, and anisotropy factor. Since Einstein gravity theory shares the same vacuum solution with Rastall gravity theory, the interior geometry is joining in a smoothly way with the exterior Schwarzschild's solution. The equilibrium of the model under different gradients is analyzed by using the modified hydrostatic equilibrium equation, containing the so called Rastall gradient. The compact structure has a positive anisotropy factor which enhances the balance and stability mechanisms. To check the potentially stable behaviour, we employ Abreu's and adiabatic index criterion. It was found that the model is completely stable. The incidence of the Rastall's parameter γ on all the physical quantities that characterize the model is described by the help of graphical analysis. Concerning the γ spectrum, we have considered $0.3142 \leq \gamma \leq 0.3157$. All the results are compared with the general relativity case. This work has been done in collaboration with Francisco Tello-Ortiz,



Ángel Rincón, and Y. Gomez-Leyton.

Charged strange star with Krori-Barua potential in $f(R, T)$ gravity admitting Chaplygin equation of state

A new compact star model in $f(R, T)$ gravity is obtained, where R and T denote the Ricci scalar and the trace of energy momentum tensor $T_{\mu\nu}$, respectively. To develop the model, we consider the spherically symmetric spacetime along with anisotropic fluid distribution in the presence of electric field with $f(R, T) = R + 2\gamma T$, where γ is a small positive constant. We have used the Chaplygin equation of state to explore the stellar model. The field equations for $f(R, T)$ gravity have been solved by employing the Krori-Barua ansatz. The exterior spacetime is described by Reissner-Nordström line element for smooth matching at the boundary. It is worth while to mention here that the values of all the constants involved with this model have been calculated for the strange stars 4U 1538-52 for different values of γ with the help of matching conditions. The acceptability of the model is discussed in detail both analytically and graphically by studying the physical attributes of matter density, pressures, anisotropy factor, stability, etc. We have also obtained the numerical values for central density, surface density, central pressure and central adiabatic index for different values of γ . The solutions of the field equations in Einstein gravity can be regained by putting $\gamma = 0$ to our solution. Moreover, the proposed model is shown to be physically admissible and corroborate with experimental observations on strange star candidates such as 4U 1538-52.

Naseer I. Bhat

Unveiling the broadband spectral and temporal properties of PKS 0903-57 during its brightest flare

We carried a detailed spectral and temporal study of blazar, PKS 0903-57 using the Fermi-LAT and Swift-XRT/UVOT observations, during its brightest flaring period MJD 58931-58970. During this period, the maximum daily averaged γ -ray flux $F_{0.1-500\text{GeV}}$ of $9.42 \times 10^{-6} \text{phcm}^{-2}\text{s}^{-1}$ is observed on MJD 58951.5, the highest γ -ray flux detected from PKS 0903-57 till now. Several high-energy (HE) photons ($> 10\text{GeV}$) consistent with the source location at high probability ($>99\%$)

are detected, and the γ -ray light curve in the active state shows multiple substructures with asymmetric profile. Neglecting the multi-band variability in each of the selected time intervals, we could reproduce their averaged broadband SEDs with a one-zone leptonic model whose parameters were derived with a χ^2 - fit. We found that the broadband SED during different flux states can be reproduced by the synchrotron, synchrotron-self-Compton (SSC), and External Compton (EC) processes. The seed photons for EC process from BLR or IR torus provide acceptable fits to the GeV spectrum in all the flux states; however, the detection of HE photons together with the equi-partition condition suggest that the EC/IR process is a more likely scenario. Further, a detailed comparison between the fit parameters shows that the flux enhancement from quiescent-state to the flaring-state is mostly related to increase in the bulk Lorentz factor of the emission region and change in the break energy of the source spectrum. This work has been done in collaboration with Zahir A. Shah, Vadakkumthani Jithesh, and Sunder Sahayanathan.

Srijit Bhattacharjee

Displacement memory effect near the horizon of black holes

We study the displacement memory effect and its connection with the extended-BMS symmetries near the horizon of black holes. There is a permanent shift in the geodesic deviation vector relating two nearby timelike geodesics placed close to the horizon of black holes, upon the passage of gravitational waves. We also relate this memory effect with the asymptotic symmetries near the horizon of asymptotic black hole spacetimes. The shift of the relative position of the detectors is shown to be induced by a combination of BMS generators near the horizon. The displacement memory effect near the horizon possesses similarities to the same obtained in the far region. This work has been done in collaboration with Shilesh Kumar, and Arpan Bhattacharyya.

Scalar perturbations of black holes in Jackiw-Teitelboim gravity

We study linear scalar perturbations of black holes in two-dimensional (2D) gravity models



with a particular emphasis on Jackiw-Teitelboim (JT) gravity. We obtain an exact expression of the quasi-normal mode frequencies for single horizon black holes in JT gravity, and then verify it numerically using the Horowitz-Hubeny method. For a 2D Reissner-Nordström like solution, we find that the massless scalar wave equation reduces to the confluent Heun equation, using which we calculate the Hawking spectra. Finally, we consider the dimensionally reduced Baados-Teitelboim-Zanelli (BTZ) black hole and obtain the exterior and interior quasi-normal modes. The dynamics of a scalar field near the Cauchy horizon mimics the behaviour of the same for the usual BTZ black hole, indicating a possible violation of the strong cosmic censorship conjecture in the near extreme limit. However, quantum effects seem to rescue strong cosmic censorship. This work has been done in collaboration with Subhdeep Sarkar, and Arpan Bhattacharyya.

Debbijoy Bhattacharya

Multiwavelength study of different flaring and low-activity states of blazar 4C+21.35

Blazars, a class of active galactic nuclei, emit over the entire accessible electromagnetic spectrum, and modelling of their broad-band spectral energy distribution (SED) is the key to constrain the underlying emission mechanisms. Here, we report the results on the one-zone leptonic emission modelling carried out on the blazar 4C+21.35 using multiwavelength data spanning over the period 2008-2018. Broad-band SED modelling using γ -ray data from Fermi-Large Area Telescope, X-ray data from Swift-XRT and AstroSat, and UV-optical data from Swift-UVOT, AstroSat, and Catalina Real-Time Transient Survey was carried out at seven different epochs, including three γ -ray flaring episodes and four quiescent periods (three long-term averaged ones and one during AstroSat observing period). Our SED modelling suggests that two compact emission regions originating at a different time outside the broad-line region and moving away from the core with variation primarily in the jet electron spectra can explain the emission from the high-, moderate-, and low-activity periods. The emissions from high- and first low-activity states are likely to have originated in the first region. The moderate- and second low-activity states are likely due to

the second emission region with fresh particle acceleration/injection at a later time. This work has been done in collaboration with Krishna Mohan, Subir Bhattacharyya, Nilay Bhatt, and C. S. Stalin.

Multiwavelength monitoring of NGC 1275 over a decade: evidence of a shift in synchrotron peak frequency and long-term multiband flux increase

We carried out a detailed study of the temporal and broad-band spectral behaviour of one of the brightest misaligned active galaxies in γ -rays, NGC 1275, utilizing 11 years of Fermi data and the available Swift and AstroSat observations. Based on the cumulative flux distribution of the γ -ray light curve, we identified four distinct activity states and noticed an increase in the baseline flux during the first three states. A similar nature of increase in the average flux was also noticed in the X-ray and UV bands. Strong flaring activity in γ -rays was noticed in the fourth state. The source was observed twice by AstroSat for shorter intervals ($\sim$ days) during longer observing ($\sim$ years) states 3 and 4. During the AstroSat observing periods, the source γ -ray flux was higher than the average flux observed during longer duration states. The increase in average baseline flux from state 1 to state 3 can be explained by considering a corresponding increase of jet particle normalization. The inverse Comptonization of synchrotron photons explained the average X-ray and γ -ray emission by jet electrons during the first three longer duration states. However, during the shorter duration AstroSat observing periods, a shift of synchrotron peak frequency was noticed, and the synchrotron emission of jet electrons explained the observed X-ray flux well. This work has been done in collaboration with Sanna Gulati, Subir Bhattacharyya, Nilay Bhatt, C. S. Stalin, et al.

Ritabrata Biswas

Repulsive gravitational force and quintessence field in $f(T)$ gravity: How anisotropic compact stars in strong energy condition behave

Recently literature is found to be enriched with studies related to anisotropic behaviours of different compact stars in the background of $f(T)$ gravity in different energy conditions. Quintessence field, as local impacts of cosmic acceleration upon the compact stars, is also very interesting in



recent studies. The quintessential field effects on the compact stars (mainly on the neutron stars with an wide range of mass distributions), repulsive gravitational effects inside the compact stars due to dark matter distribution in them, charge distribution inside them in strong energy condition, etc. are studied. All required equations of motion using anisotropic property and concept of Massachusetts Institute of Technology bag model are acquired. Black holes surrounded by quintessential matters which satisfy the additive and linearity conditions, with the form of energy tensors were proposed and the corresponding metric was derived by Kiselev, V.V. The metric, described by Krori, K. D. and Barua, J. with Reissner-Nordstrom metric is compared to find out the different numerical values of unknown parameters. The numerical values are derived and some important parameters like anisotropic stress, adiabatic constant, surface redshift, electric intensity, compactness factor, stability, etc. are analysed deeply to get a clear idea for further study on these types of stars and to understand their nature. This work has been done in collaboration with Mayukh Bandyopadhyay.

Posing constraints on the free parameters of a new model of dark energy EoS : Responses through cosmological behaviours

Since the late 1990s, observations of type Ia supernova, our universe is predicted to experience a late time cosmic acceleration. Theoretical support to this observations was intended to be built via proposition of a hypothetical fluid which staying inside the universe, and exerts negative pressure. In this alley, a popular method is to choose time dependent equation of state parameter $\omega = \frac{p}{\rho}$ and to parametrize it as a function of redshift. Again, some common families of such parametrizations are constructed, among which different members justify different properties of observed universe. Mainly, these were model dependent studies which comprise free parameters to be constrained, by different observations. In this work, a new expression for redshift parametrization is considered, and we have constrain its free parameters for two Hubble parameter vs redshift data sets. These data sets are obtained depending on two basic methodologies known as different ages method and baryonic acoustic oscillation method. Different confidence contours for our

model are located under the constraints of said data sets. Besides, different thermodynamic parameters related to the evolution of our universe are analysed. It is notified that our model indicates towards a delayed dark matter model which mimics $EoS = -1(\Lambda)$ phenomena at the present epoch. It is noticed that a possibility of future deceleration may occur for this new model. Outcomes for both the data sets are compared with each other. This work has been done in collaboration with Promila Biswas, and Parthajit Roy.

Subenoy Chakraborty

Does emergent scenario in Hořava-Lifshitz gravity demand a ghost field?

The non-singular model of the universe, i.e., emergent scenario is now very well known in cosmology. In Einstein gravity, such type of singularity free solution is possible in the context of non-equilibrium thermodynamical prescription (both in first and second order theory) with particle creation mechanism. Also, there are various models of emergent scenario in different gravity, theories. The present work is a twofold attempt namely : (i) it has been examined whether it is possible to have singularity free solution in Hořava-Lifshitz modified gravity theory, and (ii) if such singularity free solution exists then whether such solution is thermodynamically viable. It is found that perfect fluid matter distribution with phantom nature can generate such type of solution for closed and flat model. Finally thermodynamical analysis has been studied both at the apparent horizon and at any arbitrary horizon. This work has been done in collaboration with Akash Bose.

Quantum cosmology with symmetry analysis for quintom dark energy model

Quantum cosmology with quintom dark energy model has been investigated in the present work using symmetry analysis of the underlying physical system. In the background of the flat FLRW model, quintom cosmological model has been studied using Noether symmetry, and appropriate conserved charge is obtained. The Wheeler-DeWitt (WD) equation is constructed on the minisuperspace and solutions are obtained using conserved charge. This work has been done in collaboration with Sourav Dutta, and Muthusamy Lakshmanan.



Hum Chand

Intra-night optical variability of γ -ray detected narrow-line Seyfert1 galaxies

We report the first attempt to systematically characterise intra-night optical variability (INOV) of the rare and enigmatic subset of Narrow-Line Seyfert1 galaxies (NLSy1s), which is marked by detection in the γ -ray band and is, therefore, endowed with Doppler boosted relativistic jets, like blazars. However, the central engines in these two types of AGN are thought to operate in different regimes of accretion rate. Our INOV search in a fairly large and unbiased sample of 15 γ -ray NLSy1s was conducted in 36 monitoring sessions, each lasting ≥ 3 hrs. In our analysis, special care has been taken to address the possible effect on the differential light curves, of any variation in the seeing disc during the session, since that might lead to spurious claims of INOV from such AGN due to the possibility of a significant contribution from the host galaxy to the total optical emission. A duty cycle (DC) of INOV detection in the γ -ray NLSy1s is estimated to be around 25% - 30%, which is comparable to that known for blazars. This estimate of DC will probably need an upward revision, once it becomes possible to correct for the dilution of the AGN's non-thermal optical emission by the (much steadier) optical emission contributed not only by the host galaxy but also the nuclear accretion disc in these high Eddington rate accretors. Finally, we also draw attention to the possibility that sharp optical flux changes on sub-hour time scale are less rare for γ -ray NLSy1s, in comparison to blazars. This work has been done in collaboration with Vineet Ojha, and Gopal-Krishna.

A comparison of X-ray photon indices among the narrow- and broad-line Seyfert 1 galaxies

We present a detailed comparative systematic study using a sample of 221 narrow-line Seyfert 1 (NLSy1) galaxies in comparison to a redshift matched sample of 154 broad-line Seyfert 1 (BLSy1) galaxies based on their observations using *ROSAT* and/or *XMM-Newton* telescopes in soft X-ray band (0.1-2.0 keV). A homogeneous analysis is carried out to estimate their soft X-ray photon indices (Γ_X^s) and its correlations with other parameters of nuclear activities such as Eddington ratios (R_{Edd}), bolometric luminosities (L_{bol}), black

hole masses (M_{BH}) and the widths of the broad component of H β lines (FWHM(H β)). We found clear evidence of the difference in the Γ_X^s and R_{Edd} distributions among NLSy1 and BLSy1 galaxies, with steeper Γ_X^s and higher R_{Edd} for the former. Such a difference also exists in the spectral indices distribution in hard X-ray (Γ_X^h), based on the analysis of 53 NLSy1 and 46 BLSy1 galaxies in the 2-10 keV energy band. The difference in R_{Edd} distributions does exist even after applying the average correction for the difference in the inclination angle of NLSy1 and BLSy1 galaxies. We also estimated R_{Edd} , based on SED fitting of 34 NLSy1 and 30 BLSy1 galaxies over the 0.3-10 keV energy band and found that results are still consistent with R_{Edd} estimates based on the optical bolometric luminosity. Our analysis suggests that the higher R_{Edd} in NLSy1 is responsible for its steeper X-ray spectral slope compared to the BLSy1, consistent with the disc-corona model as proposed for the luminous AGNs. These observations have been done in collaboration with Vineet Ojha, Gulab C. Dewangan, and Suvendu Rakshit.

Ramesh Chandra

Variation of chromospheric features as a function of latitude and time using Ca-K spectroheliograms for solar cycles 15 - 23: Implications for meridional flow

We have analyzed the Ca-K images obtained at Kodaikanal Observatory as a function of latitude and time for the period of 1913 - 2004 covering solar cycles 15 to 23. We have classified the chromospheric activity into plage, Enhanced Network (EN), Active Network (AN), and Quiet Network (QN) areas to differentiate between large strong active and small weak active regions. The strong active regions represent toroidal and weak active regions poloidal component of the magnetic field. We find that plage areas mostly up to 50° latitude belt vary with about 11-year solar cycle. We also find that a weak activity represented by EN, AN and QN varies with about 11-year with significant amplitude up to about 50° latitude in both hemispheres. The amplitude of the variation is minimum around 50° latitude and again increases by a small amount in the polar region. In addition, the plots of plages, EN, AN and QN as functions of time indicate the



maximum of activity at different latitude occur at different epoch. To determine the phase difference for the different latitude belts, we have computed the cross-correlation coefficients of other latitude belts with the 35° latitude belt. We find that the activity shifts from mid-latitude belts towards equatorial belts at high speed at the beginning of a solar cycle and at lower speed as the cycle progresses. The speed of the shift varies between ≈ 19 and $3 \text{ (ms}^{-1}\text{)}$ considering all the data for the observed period. This speed can be linked with the speed of meridional flows, believed to occur between convection zone and the surface of the Sun. This work has been done in collaboration with Pooja Devi, Jagdev Singh, Muthu Priyal, and Reetika Joshi.

Observations of a eruption and loop contraction

Prominence eruptions provide key observations to understand the launch of coronal mass ejections as their cold plasma traces a part of the unstable magnetic configuration. We select a well observed case to derive observational constraints for eruption models. We analyze the prominence eruption and loop expansion and contraction observed on 02 March 2015 associated with a GOES M3.7 class flare (SOL2015-03-02T15:27) using the data from Atmospheric Imaging Assembly (AIA) and the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI). The source region is a decaying bipolar active region where magnetic flux cancellation is present for several days before the eruption. AIA observations locate the erupting prominence within a flux rope viewed along its local axis direction. We identify and quantify the motion of loops in contraction and expansion located on the side of the erupting flux rope. Finally, RHESSI hard X-ray observations identify the loop top and two foot-point sources. Both AIA and RHESSI observations support the standard model of eruptive flares. The contraction occurs 19 min after the start of the prominence eruption indicating that this contraction is not associated with the eruption driver. Rather, this prominence eruption is compatible with an unstable flux rope, where the contraction and expansion of the lateral loop is the consequence of a side vortex developing after the flux rope is launched. These observations have been done in collaboration with Pooja Devi, Pascal Demoulin, Reetika Joshi, Brigitte Schmieder, et al.

Suresh Chandra

Investigation of hydrogen peroxide (H_2O_2) in the interstellar medium

In view of the important role of hydrogen peroxide (H_2O_2) in the chemistry of ozone layer in troposphere, and as an oxidizer on the planet Mars, its investigation has been carried out from time to time. It has been detected in the cold environment of a star-forming region towards ρ Oph A. Following the selection rules, in the ground vibrational state, its ro-torsional levels may be classified into four distinct groups. Using the spectroscopic information (rotational and centrifugal distortion constants, and electric dipole moment), we have calculated energies of the lower 50 levels of each group, and the radiative transition probabilities for the transitions between the levels. Using these radiative transition probabilities along with the collisional rate coefficients (obtained with the help of a scaling law) we have solved, for each group, a set of 50 statistical equilibrium equations coupled with the equations of radiative transfer and have found 16 lines showing anomalous absorption. In addition to 4 detected lines, 24 lines are found to show emission feature. All these lines may play a significant role for the identification of H_2O_2 in the interstellar medium.

Suggestion for the search of diisocyanomethane (CNCH_2NC) in the cosmic object: Potential spectral lines

Finding several molecules having cyanide group ($-\text{C}\equiv\text{N}$) and isocyanide group ($-\text{N}\equiv\text{C}$), scientists searching for life in the universe, are interested in the molecules having two cyanide or isocyanide groups. Diisocyanomethane (CNCH_2NC) having two isocyano groups is an interesting candidate for the astronomers, though it has not been detected in any cosmic object. However, three organic isocyanides (HNC , CH_3NC , HCCNC) have been found in the interstellar medium (ISM). Submillimeter wave spectrum of CNCH_2NC is analyzed by spectroscopists, so that it could be searched in the ISM. For searching CNCH_2NC in a cosmic object, information about its strong spectral lines is essential. The rotational levels of CNCH_2NC can be classified into two species. The energies of lower 250 rotational levels up to 108 cm^{-1} , in the ground vibrational state, and the radiative transition probabilities for rotational



transitions in each species are calculated by using the values of rotational and centrifugal distortion constants along with the electric dipole moment. A set of statistical equilibrium equations coupled with the equations of radiative transfer is solved by using the radiative transition probabilities and the scaled values of collisional rate coefficients as input data. For each species, we have found two transitions showing emission feature and four transitions showing anomalous absorption. These 12 transitions may help in the detection of CNCH₂NC in a cosmic object.

Ayan Chatterjee

Marginally trapped surfaces in spherical gravitational collapse

This work deals with a detailed study of horizons during the gravitational collapse of dust and viscous fluids, under the assumptions of spherical symmetry. The formation and time evolution of collapsing shells, spherically symmetric marginally trapped tubes, as well as the event horizon are determined and compared through analytical and numerical techniques. Using different density profiles of matter, we analyze how the nature of these marginally trapped surfaces modify as we change the energy-momentum tensor. These studies reveal that depending on the mass function and the mass profile, it is possible to envisage situations where dynamical horizons, timelike tubes, or isolated horizons arise. This work has been done in collaboration with Amit Ghosh, and Suresh C. Jaryal.

Exponential corrections to black hole entropy

Using the quasi-local properties alone we show that the area spectrum of a black hole horizon must be discrete, independent of any specific quantum theory of gravity. The area spectrum is found to be half-integer spaced with values $8\gamma\ell_P^2 j$, where $j \in N/2$. We argue that if microstate counting is carried out for quantum states residing on the horizon only, correction of $\exp(-\mathcal{A}/4\ell_P^2)$ over the Bekenstein-Hawking area law must arise in black hole entropy. This work has been done in collaboration with Amit Ghosh.

Ritaban Chatterjee

Blazar variability: A study of non-stationarity and the flux-RMS relation

We analyze X-ray light curves of the blazars Mrk 421, PKS 2155-304, and 3C 273 using observations by the Soft X-ray Telescope on board AstroSat and archival XMM-Newton data. We use light curves of length 30-90 ks each from 3-4 epochs for all three blazars. We apply the auto-regressive integrated moving average (ARIMA) model, which indicates the variability is consistent with short memory processes for most of the epochs. We show that the power spectral density (PSD) of the X-ray variability of the individual blazars are consistent within uncertainties across the epochs. This implies that the construction of broadband PSD using light curves from different epochs is accurate. However, using certain properties of the variance of the light curves and its segments, we show that the blazars exhibit hints of non-stationarity beyond that due to their characteristic red noise nature in some of those observations. We find a linear relationship between the root-mean-squared amplitude of variability at shorter time scales and the mean flux level at longer time scales for light curves of Mrk 421 across epochs separated by decades as well as light curves spanning 5 days and ~ 10 yr. The presence of flux-rms relation over very different time scales may imply that, similar to the X-ray binaries and Seyfert galaxies, longer and shorter time scale variability are connected in blazars. This study has been done in collaboration with Souradip Bhattacharyya, Ritesh Ghosh, and Nabanita Das.

Surajit Chattopadhyay

Reconstructed $f(R)$ gravity and its cosmological consequences in chameleon scalar field with a scale factor describing the pre-bounce ekpyrotic contraction

The present study reports a reconstruction scheme for $f(R)$ gravity with the scale factor $a(t) \propto (t_* - t)^{\frac{2}{c^2}}$, describing the pre-bounce ekpyrotic contraction, where t_* is the big crunch time. The reconstructed $f(R)$ is used to derive expressions for density and pressure contributions and the equation of state parameter resulting from this reconstruction is found to behave like "quintom". It has also been observed that



the reconstructed $f(R)$ has satisfied a sufficient condition for a realistic model. In the subsequent phase, the reconstructed $f(R)$ is applied to the model of chameleon scalar field and the scalar field ϕ and the potential $V(\phi)$ are tested for quasi-exponential expansion. It has been observed that although the reconstructed $f(R)$ satisfies one of the sufficient conditions for realistic model, the quasi-exponential expansion is not available due to this reconstruction. Finally, the consequences pre-bounce ekpyrotic inflation in $f(R)$ gravity are compared to the background solution for $f(R)$ matter bounce. This work has been done in collaboration with Soumyodipta Karmakar, Kairat Myrzakulov, and Ratbay Myrzakulov.

Cosmology of Tsallis holographic scalar field models in Chern-Simons modified gravity and optimization of model parameters through χ^2 minimization

The present study reports reconstruction schemes for tachyon, k-essence and dilaton scalar field model of Dark Energy (DE) through Tsallis holographic dark fluid under the framework of Chern-Simons modified gravity. Reproducing the conservation equation for a coupled model with interaction term $Q = 3Hb^2\rho_m$, we have reconstructed the different scalar fields and the corresponding potentials. In the case of tachyon, Λ CDM fixed point is attained under this cosmological settings. Considering k-essence in this interacting situation we have derived some constraints on the interaction term as well as Tsallis holographic dark energy parameter. Reconstructing dilaton scalar field we have studied the behaviour of scalar field and potential. In all these cases, the reconstructed Equation of State (EoS) parameters have been plotted and when computed for current universe $z = 0$ are found to be consistent with various observational data including *Planck* + *WP* + *BAO*. The only exception is a particular case of reconstructed k-essence model where phantom behaviour is apparent, but its numerical value is deviated from the bounce set by the observations. Finally, we have developed a functional relationship between Hubble parameter and redshift and optimized the parameter values through χ^2 minimization using the observed Hubble parameter values from Hai Yu, et al. 2018, *ApJ*, **856**, 3. This work has been done in collaboration with Gargee Chakraborty.

Tanuka Chattopadhyay

A study on the formation of field, binary or multiple stars: A 2D approach through dynamical system

A dynamical model has been developed to envisage the star formation scenario in filamentary molecular clouds. In the present work, a double well potential has been considered to find the number of stable stationary points as the origin of field star, binary stars or stellar associations. It is found that low density structure can lead to the formation of field stars while an intermediate density structure is favourable for formation of binary stars. Stellar associations are generally prevalent in dense filamentary molecular clouds. This work has been done in collaboration with Ashok Mondal, and Anisha Sen.

Exploration of the origin of galactic and extragalactic star clusters through simulated H-R diagrams

This work explores the origin of the formation of star clusters in our Galaxy and in the Small Magellanic Cloud (SMC) through simulated H-R diagrams and compare those with observed star clusters. The simulation study produces synthetic H-R diagrams through the Markov Chain Monte Carlo (MCMC) technique using the star formation history (SFH), luminosity function (LF), abundance of heavy metal (Z), and a big library of isochrones as basic inputs and compares them with observed H-R diagrams of various star clusters. The distance-based comparison between those two diagrams is carried out through two-dimensional matching of points in the colour-magnitude diagram (CMD) after the optimal choice of bin size and appropriate distance function. It is found that in a poor medium of heavy elements ($Z = 0.0004$), the Gaia LF along with a mixture of multiple Gaussian distributions of the SFH may be the origin of formation of globular clusters (GCs). On the contrary, an enriched medium ($Z = 0.019$) is generally favoured with the Gaia LF along with a double power law or Beta-type (i.e., unimodal) SFH, for the formation of globular clusters. For SMC clusters, the choice of an exponential LF and exponential SFH is the proper combination for a poor medium, whereas the Gaia LF with a Beta-type SFH is preferred for the formation of star clusters in an enriched



medium. This work has been carried out with Sreerup Mondal, Suman Paul, Subhadip Maji, and Asis Chattopadhyay.

Himadri S. Das

The Umov effect in cosmic dust analogue fluffy aggregates

We investigate the effect of porosity in the Umov effect for the first time using the aggregate dust model. Three different types of fractal aggregates: ballistic agglomeration (BA), ballistic agglomeration with one migration (BAM1), and ballistic agglomeration with two migrations (BAM2) having porosities 0.87, 0.74 and 0.64, respectively (which have the same characteristic radius $\sim 1\mu m$) are considered in our simulations. Using the multi-sphere T-matrix (MSTM) code, maximum positive polarization (P_{max}) and geometric albedo (A) are calculated for three different fractal aggregated structures considering amorphous silicate composition. Then P_{max} and A are plotted against each other in logarithmic scale, which shows a linear inverse correlation and a strong porosity dependence. Further, we explore the effect of aggregate size parameter and the effect of composition in the Umov diagram for particles larger than the wavelength of incident radiation. This work has been done in collaboration with Ayesha M. Mazarbhuiya, and Prithish Halder.

Shyam Das

Modeling of compact stars: An anisotropic approach

We present a new class of singularity free interior solutions relevant for the description of realistic anisotropic compact stellar objects with spherically symmetric matter distribution. In this geometric approach, specific choices of one of the metric functions and a selective anisotropic profile allow us to develop a stellar model by solving Einstein Field equations. The interior solutions, thus, obtained are matched with the Schwarzschild exterior metric over the bounding surface of a compact star. These matching conditions together with the condition that the radial pressure vanishes at the boundary are used to fix the model parameters. The different physical features for the developed model explicitly studied from

the aspect of the pulsar 4U1820 – 30 with its current estimated data (mass = $1.58 M_{\odot}$ and radius = 9.1 km). Analysis has shown that all the physical aspects are acceptable demanded for a physically admissible star and satisfy all the required physical conditions. The stability of the model is also explored in the context of causality conditions, adiabatic index, generalized Tolman-Oppenheimer-Volkov (TOV) equation, Buchdahl Condition and Herrera Cracking Method. To show that the developed model is compatible with a wide range of recently observed pulsars, various relevant physical variables are also highlighted in tabular form. Assuming a particular surface density ($7.5 \times 10^{14} \text{ gm cm}^{-3}$), the mass-radius ($M - b$) relationship and the radius-central density relationship ($b - \rho(0)$) of the compact stellar object are analyzed for this model. Additionally, comparing the results with a slow rotating configuration, we have also discussed moment of inertia and the time period using Bejger-Haensel idea. This work has been done in collaboration with Ksh. Newton Singh, Lipi Baskey, Farook Rahaman, and Anil K. Aria.

Anisotropic compact stellar model of embedding class-I satisfying Karmarkar's condition in Vaidya and Tikekar spheroidal geometry

Making use of the Vaidya and Tikekar (VT) metric ansatz for one of the metric functions g_{rr} , we obtain the unknown metric function g_{tt} by utilizing the Karmarkar's embedding condition. The model parameters are fixed by using the matching conditions of the interior spacetime and the exterior Schwarzschild spacetime at the boundary of the star where the radial pressure vanishes. The closed-form interior solution of the Einstein field equations, thus, obtained is shown to be capable of describing observed pulsars like 4U1820 – 30. The current estimated masses and radii of some other pulsars are also utilized to show that the developed model meets all the requirements of a realistic star. The dependence of the curvature parameter K of the VT model, which characterizes a departure from homogeneous spherical distribution, is investigated in the context of the mass-radius relationship of a compact star. This work has been done in collaboration with Ranjan Sharma, Koushik Chakraborty, and Lipi Baskey.



Ujjal Debnath

Thermodynamics of FRW universe: Heat engine

We assume the cosmological horizon as a inner trapping horizon, which is treated as dynamical apparent horizon of FRW universe. We write the dynamical apparent horizon, radius and temperature on the apparent horizon. We assume that the fluid pressure as thermodynamical pressure of the system. Using Hayward's unified first law, Clausius relation and Friedmann equations with cosmological constant, we obtain the entropy on the apparent horizon. We assume that the cosmological constant provides the thermodynamic pressure of the system. We obtain the entropy, surface area, volume, temperature, Gibb's Helmholtz's free energies, specific heat capacity of the FRW universe due to the thermodynamic system. We study the Joule-Thomson expansion, and by evaluating the positive sign of Joule-Thomson coefficient, we determine that the FRW universe obeys the cooling nature. We also find the inversion temperature and inversion pressure. For Carnot cycle, we obtain the work done and the maximum efficiency. Also for new engine, we study the work done and its efficiency.

Constraining the parameters of modified Chaplygin gas in Brans-Dicke theory

We have explored the modified Chaplygin gas (MCG) in the background of Brans-Dicke theory in presence of radiation and dark matter. We have assumed that the MCG, radiation and dark matter are conserved separately. To investigate the fitting observational data, we constrain the model using current observations and then compare with Λ CDM model in Einstein's gravity and in BD theory using the information criteria (AIC and BIC). We have used the JLA sample of SNIa observation, Planck 2015 data of CMB observation, BAO data and Hubble constant H_0 measurement. The best fit parameters for Λ CDM model and MCG model in BD theory are obtained by SNIa+CMB+BAO+ H_0 joint data analysis. Also, the minimum values of χ^2 function have been calculated. We have plotted the contour figures for different confidence levels 66%, 90% and 99% in Λ CDM model and MCG model separately. Finally, we have analyzed Δ AIC and Δ BIC for Λ CDM and MCG models in Einstein's gravity and in BD

theory.

Shantanu Desai

Constraints on the variation of fine structure constant from joint SPT-SZ and XMM-Newton observations

We search for a variation of the electromagnetic fine structure constant ($\alpha \equiv e^2/\hbar c$) using a sample of 58 SZ selected clusters in the redshift range ($0.2 < z < 1.5$) detected by the South Pole Telescope, along with X-ray measurements using the XMM-Newton observatory. We use the ratio of the integrated SZ Compton-ionization to its X-ray counterpart as our observable for this search. We first obtain a model-independent constraint on α of about 0.7%, using the fact that the aforementioned ratio is constant as function of redshift. We then look for logarithmic dependence of α as a function of redshift: $\Delta\alpha/\alpha = -\gamma \ln(1+z)$, as this is predicted by runaway dilaton models. We find that $\gamma = -0.046 \pm 0.1$, which indicates that there is no logarithmic variation of α as a function of redshift. We also search for a dipole variation of the fine structure constant using the same cluster sample. We do not find any evidence for such a spatial variation. This evaluation has been done in collaboration with Kamal Bora.

Yet another test of radial acceleration relation for galaxy clusters

We carry out a test of the radial acceleration relation (RAR) for galaxy clusters from two different catalogues compiled in literature, as an independent cross-check of two recent analyses, which reached opposite conclusions. The datasets we considered include a Chandra sample of 12 clusters and the X-COP sample of 12 clusters. For both the samples, we find that the residual scatter is small (0.11-0.14 dex), although the best-fit values for the Chandra sample have large error bars. Therefore, we argue that at least one of these cluster samples (X-COP) obeys the radial acceleration relation. However, since the best-fit parameters are discrepant with each other as well as the previous estimates, we argue that the RAR is not universal. For both the catalogues, the acceleration scale, which we obtain is about an order of magnitude larger than that obtained for galaxies, and is agreement with both the recent estimates. This work has been done in



collaboration with S. Pradyumnaa, Sajal Gupta, and Sowmya Seerama.

Shanti P. Devarapalli

Photometric investigation of eight ultra-short period eclipsing binaries from OGLE

We performed a detailed photometric analysis of eight ultra-short period eclipsing binaries (USPEBs) using the Wilson-Devinney method. We presented the modelled light curves and derived photometric solutions. The USPEBs with period (P) ≤ 0.21 d considered in our study belong to W-subtype having - shallow contact factor (f) $< \sim 20\%$, high mass ratios (q) $> \sim 0.7$, and later spectral types. The absolute parameters for these short-period binaries were derived using empirical relations. We discussed the evolutionary stage of these USPEBs using the mass-radius, colour-density, and period-colour diagrams. The objects showed poor metallicities, and some objects were even found to be existing around fully convective limits. The period distribution of USPEBs exhibited a sharp cut-off at 0.22 days; however, we observed significant deficits for our objects in the literature. We examined the statistics of USPEBs studied to date (in terms of the distribution of period, mass ratio, and component temperatures of USPEBs), and observed that a dominant distribution of component temperatures of these USPEBs was towards lower temperatures. This work has been done in collaboration with P. Ravi Raja, Rukmini Jagirdar, M. Raghu Prasad, and Vinit Thomas.

Moon M. Devi

DIREXENO-An apparatus for measuring correlated scintillation signatures in liquid xenon

We present a detector apparatus, DIREXENO (DIREctional XENOn), designed to measure the spatial and temporal properties of scintillation in liquid xenon to very high accuracy. The properties of scintillation are of primary importance for dark matter and neutrinoless double beta decay experiments; however, the complicated microphysics involved limits theoretical predictions. We explore the possibility that scintillation emission exhibits spatial correlations such as super-radiance, which manifests in temporal and spatial structure, depending on the

interaction type. Such properties of scintillation light may open a new window for background rejection as well as directionality measurements. We present the apparatus' technical design and the concepts driving it. We demonstrate that for an energy deposition of ~ 2.5 keV (~ 7.5 keV) electron (nuclear) recoil the detector is sensitive to an anisotropy fraction of as little as $\sim 20\%$ of the total photons emitted over a solid angle of ~ 0.85 steradian or less. We show results from commissioning runs in which the detector operated with 17 PMTs for over 44 days in stable conditions. The time resolution for individual photons in different PMTs was measured to be ≤ 1.4 ns full-width at half-maximum. This work has been done in collaboration with Ran Itay, P.Z. Szabo, G. Koltman, M. Shutman, et al.

Supernova model discrimination with Hyper-Kamiokande; HK collaboration

Core-collapse supernovae are among the most magnificent events in the observable universe. They produce many of the chemical elements necessary for life to exist and their remnants – neutron stars and black holes – are interesting astrophysical objects in their own right. However, despite millennia of observations and almost a century of astrophysical study, the explosion mechanism of core-collapse supernovae is not yet well understood. Hyper-Kamiokande is a next-generation neutrino detector that will be able to observe the neutrino flux from the next galactic core-collapse supernova in unprecedented detail. We focus on the first 500 ms of the neutrino burst, corresponding to the accretion phase, and use a newly-developed, high-precision supernova event generator to simulate Hyper-Kamiokande's response to five different supernova models. We show that Hyper-Kamiokande will be able to distinguish between these models with high accuracy for a supernova at a distance of up to 100 kpc. Once the next galactic supernova happens, this ability will be a powerful tool for guiding simulations towards a precise reproduction of the explosion mechanism observed in nature.

Vijayakumar H. Doddamani

A study of magnetic imprints of solar flares

We made a systematic analysis of flare related changes of photospheric magnetic properties



during 12 flares using the high cadence of 135 s vector-magnetogram data obtained from Helioseismic Magnetic Imager on-board Solar Dynamics Observatory. We observed the change of Lorentz force implied by the rapid step-wise enhancement of the horizontal component of magnetic field during all flares in the sample. The integrated change of fields and total change of Lorentz force over an area signifying the strength of magnetic imprints are well correlated with the flare strength and the CME momentum. It is found that the strength of magnetic imprints are not stronger for eruptive flares in comparison with non-eruptive flares. Further, the temporal evolution of magnetic energy of the source active regions exhibit the nearly step-wise decrease of magnetic free energy during the flares. The amount of decrease in free energy during the flares has a strong positive correlation (0.8) with downward impulse resulted from the total change of Lorentz force indicating that the part of energy released during flares would penetrate into the photosphere. These results strongly favour the idea of significant feedback from corona on the photospheric magnetic field during flares. On contrary to these results, we observed the simultaneous step-wise increase and decrease of horizontal magnetic field during flares led to the cancellation of impulsive Lorentz force, thought to provide the CME momentum. These contradictions indicate that present understanding of flare associated magnetic field changes is limited and hints the need of further improvement of coronal implosion model. This study has been done in collaboration with N. Vasantharaju, P. Vemareddy, and B. Ravindra.

UV Spectroscopic study of PG 1634+706 and PG 1241+176 using IUE Data

We present our results on the UV continuum variability studies of two QSOs PG 1241 + 176 ($z = 1.27$), and PG 1634 + 706 ($z = 1.33$) using the final archival data. In PG 1241+176, we have found the values of R_{max} and F_{var} to 1.23, 1.12, 1.14, 1.11, and 7 %, 4 %, 6 %, and 4 % respectively corresponding to the UV continuum windows 1050-1100 Å, 1170-1190 Å, 1280-1300 Å, 1320-1340 Å, and 1360-1380 Å. The decrease in variability amplitude with increasing wavelength resembles the similar variability pattern observed in many actives galaxies such as NGC 4151, NGC 7469 and NGC 5548 observed by IUE in UV region,

optical region by many ground based telescopes and in X-rays by space bound observatories like ROSAT and GINGA. In PG 1634+706, the values of R_{max} and F_{var} have been found to be 1.5, 2.6, 1.8, and 2.1, and 10 %, 29 %, 13 % and 29 % for the UV continua at 1075 Å, 1180 Å, 1290 Å, 1330 Å, and 1370 Å respectively. PG 1634+706 has exhibited non-trendy continuum variability pattern in R_{max} and F_{var} parameters. A detailed discussion on the UV data, analysis and the significance results on high redshift UV observations are presented in this paper. This study has been done in collaboration with Bryan R. Miranda, and P. Vedavathi.

Broja G. Dutta

Time-domain variability properties of XTE J1650500 during its 2001 outburst: Evidence of discjet connection

The evolution of variability properties of galactic transient sources is a diagnostic tool to understand various regimes of the accretion flow and its dynamics close to the central black hole. In this work, we concentrate on the variability properties of the X-ray transient XTE J1650500, and investigate the evolution of viscous delay, time lag, quasi-periodic oscillation (QPO) frequency, and their energy dependence throughout the rising phase as observed by Rossi X-ray Timing Explorer (RXTE) during its outburst in 2001. Our analysis reveals, (i) a delay of 12 ± 1 d between 1 d-averaged hard (512 keV) and soft (1.53 keV) photon light curves as observed by RXTE/ASM; (ii) QPOs with high rms values are observed in lower energy (48 keV) range; (iii) the QPO frequencies and associated time lags were anticorrelated during the initial days of the rising phase, and later on, they were found to be correlated; and (iv) the time lags of Fe-line photons with respect to hard and soft photons remained almost constant during the initial days of hard state and the lag magnitude increased during the state transition. We perform comparative studies with outbursts of GX 3394 and XTE J1550564. We find the evolution of time lags associated with the QPO characteristics during the outburst stronger QPOs at low energy and constant lags of broad Fe-line photons present a unique nature of outburst profile in XTE J1650500. The possible cause of such variabilities is explained by considering discjet geometry closer to the central black hole. This work has been done in



collaboration with Arka Chatterjee, Prantik Nandi, and Sandip K. Chakrabarti .

Jibitesh Dutta

Cosmological solutions and growth index of matter perturbations in $f(Q)$ gravity

We study one of Einstein's alternative formulations based on the non-metricity scalar Q generalized as $f(Q)$ theory. More specifically, we consider the power-law form of $f(Q)$ gravity, i.e., $f(Q) = Q + \alpha Q^n$. Here, we analyze the behaviour of the cosmological model at the background and perturbation level. At the background level, the effective evolution of the model is the same as that of the Λ CDM for $|n| < 1$. Interestingly, the geometric component of the theory solely determined the late-time acceleration of the universe. We also examine the integrability of the model by employing the method of singularity analysis. In particular, we find the conditions under which field equations pass the Painlevé test, and hence, possess the Painlevé property. While the equations pass the Painlevé test in the presence of dust for any value of n , the test is valid after the addition of radiation fluid only for $n < 1$. Finally, at the perturbation level, the behaviour of matter growth index signifies a deviation of the model from the Λ CDM even for $|n| < 1$. This study has been done in collaboration with Wompherdeiki Khylllep, and Andronikos Paliathanasis.

Cosmological dynamics and bifurcation analysis of the general non-minimally coupled scalar field models

Non-minimally coupled scalar field models are well-known for providing interesting cosmological features. These include a late time dark energy behaviour, a phantom dark energy evolution without singularity, an early time inflationary universe, scaling solutions, convergence to the standard Λ CDM, etc. While the usual stability analysis helps us determine the evolution of a model geometrically, bifurcation theory allows us to precisely locate the parameters' values describing the global dynamics without a fine-tuning of initial conditions. Using the centre manifold theory and bifurcation analysis, we show that the general model undergoes a transcritical bifurcation, which predicts us to tune our models to have certain desired dynamics. We obtained a class of models

and a range of parameters capable of describing a cosmic evolution from an early radiation era towards a late time dark energy era over a wide range of initial conditions. There is also a possible scenario of crossing the phantom divide line. We also find a class of models where the late time attractor mechanism is indistinguishable from that of a structurally stable general relativity based model; thus, we can elude the big rip singularity generically. Therefore, bifurcation theory allows us to select models that are viable with cosmological observations. This study has been done in collaboration with Wompherdeiki Khylllep.

Abhik Ghosh

Demonstrating the Tapered Gridded Estimator (TGE) for the cosmological HI 21-cm power spectrum using 150 MHz GMRT observations

We apply the Tapered Gridded Estimator (TGE) for estimating the cosmological 21-cm power spectrum from 150MHz GMRT observations which corresponds to the neutral hydrogen (HI) at redshift $z = 8.28$. Here, TGE is used to measure the Multi-frequency Angular Power Spectrum (MAPS) $C_\ell(\Delta\nu)$ first, from which we estimate the 21-cm power spectrum $P(k_\perp, k_\parallel)$. The data here, are much too small for a detection, and the aim is to demonstrate the capabilities of the estimator. We find that the estimated power spectrum is consistent with the expected foreground and noise behaviour. This demonstrates that this estimator correctly estimates the noise bias, and subtracts this out to yield an unbiased estimate of the power spectrum. More than 47% of the frequency channels had to be discarded from the data owing to radio-frequency interference, however, the estimated power spectrum does not show any artifacts due to missing channels. Finally, we show that it is possible to suppress the foreground contribution by tapering the sky response at large angular separations from the phase centre. We combine the k modes within a rectangular region in the 'EoR window' to obtain the spherically binned averaged dimensionless power spectra $\Delta^2(k)$ along with the statistical error σ associated with the measured $\Delta^2(k)$. The lowest k -bin yields $\Delta^2(k) = (61.47)^2 \text{K}^2$ at $k = 1.59 \text{Mpc}^{-1}$, with $\sigma = (27.40)^2 \text{K}^2$. We obtain a 2σ upper limit of $(72.66)^2 \text{K}^2$ on the mean squared HI 21-cm brightness temperature



fluctuations at $k = 1.59 \text{ Mpc}^{-1}$. This work has been done in collaboration with Srijita Pal, Somnath Bharadwaj, and Samir Choudhuri.

Tight constraints on the excess radio background at $z = 9.1$ from LOFAR

The ARCADE2 and LWA1 experiments have claimed an excess over the Cosmic Microwave Background (CMB) at low radio frequencies. If the cosmological high-redshift contribution to this radio background is between 0.1% and 22% of the CMB at 1.42 GHz, it could explain the tentative EDGES low-band detection of the anomalously deep absorption in the 21-cm signal of neutral hydrogen. We use the upper limit on the 21-cm signal from the epoch of reionization ($z = 9.1$) based on 141 hours of observations with LOFAR to evaluate the contribution of the high redshift Universe to the detected radio background. Marginalizing over astrophysical properties of star-forming halos, we find (at 95% C.L.) that the cosmological radio background can be at most 9.6% of the CMB at 1.42 GHz. This limit rules out strong contribution of the high-redshift Universe to the ARCADE2 and LWA1 measurements. Even though LOFAR places limit on the extra radio background, excess of 0.1 – 9.6% over the CMB (at 1.42 GHz) is still allowed and could explain the EDGES Low-Band detection. We also constrain the thermal and ionization state of the gas at $z = 9.1$, and put limits on the properties of the first star-forming objects. We find that, in agreement with the limits from EDGES high-band data, LOFAR data constrain scenarios with inefficient X-ray sources, and cases where the Universe was ionized by stars in massive halos only. This work has been done in collaboration with Rittik Mondal, Anastasia Fialkov, C. Fling, and Ilian. T. Iliev, et al.

Suman Ghosh

Particle creation by a massless spin- $\frac{1}{2}$ field in a warped cosmological braneworld scenario

Energy momentum tensor, of a quantised massless bulk spin- $\frac{1}{2}$ field in five dimensional warped cosmological spacetimes is studied. The four dimensional part of our model represents a warped cosmological thick brane and the scale of the extra dimension is time-dependent. We use a simple ansatz to solve the Dirac equation in the bulk

that helps us to compare our results with the known four dimensional case. Renormalisation of the components of the energy momentum tensor is achieved using adiabatic regularization method. We compute the leading order finite contribution to the stress-energy tensor, which is of adiabatic order six. The resulting energy and pressure densities explicitly show the effects of the so-called warping factor and the dynamic extra dimension on the created matter. We show how the energy density produced is localised to form 3-branes along the extra dimension.

Sushant G. Ghosh

Parameters estimation and strong gravitational lensing of non-singular Kerr-Sen black holes

The recent time witnessed a surge of interest in strong gravitational lensing by black holes, and is due to the Event Horizon Telescope (EHT) results, which suggest comparing the black hole lensing in both general relativity and heterotic string theory. That may help us to assess the phenomenological differences between these models. Motivated by this, we consider gravitational lensing by the non-singular Kerr-Sen black holes, which encompass Kerr black holes as a particular case, to calculate the light deflection coefficients in strong-field limits p and q , while the former increases with increasing parameters b and charge k , later decrease. We also find a decrease in the light deflection angle α_D , angular position θ_∞ decreases more slowly, and impact parameter for photon orbits u_m more quickly, but angular separation s increases more rapidly with parameters b and k . We compare our results with those for Kerr black holes, and also the formalism is applied to discuss the astrophysical consequences in the case of the supermassive black holes NGC 4649, NGC 1332, Sgr A*, and M87*. In turn, we also investigate the shadows of the non-singular Kerr-Sen black holes, and show that they are smaller and more distorted than the corresponding Kerr black holes and non-singular Kerr black holes shadows. The inferred circularity deviation $\Delta C \leq 0.10$, for the M87* black hole shadow, put constraints on the non-singular Kerr-Sen black hole parameters (a, k) and (a, b) . The maximum shadow angular diameter for $b = 0.30M$ and $k = 0.30M$ are respectively, $\theta_d = 35.346 \mu\text{as}$ and $\theta_d = 35.3355 \mu\text{as}$. We also estimate the parameters



associated with non-singular Kerr–Sen black holes using the shadow observables. This work has been done in collaboration with Rahul Kumar, and shafqat ul Islam.

Testing rotating regular metrics as candidates for astrophysical black holes

The Event Horizon Telescope, a global sub-millimeter wavelength very long baseline interferometry array, produced the first image of supermassive black hole M87* showing a ring of diameter $\theta_d = 42 \pm 3 \mu\text{as}$, inferred a black hole mass of $M = (6.5 \pm 0.7) \times 10^9 M_\odot$ and allowed us to investigate the nature of strong-field gravity. The observed image is consistent with the shadow of a Kerr black hole, which according to the Kerr hypothesis describes the background spacetimes of all astrophysical black holes. The hypothesis, a strong-field prediction of general relativity, may be violated in the modified theories of gravity that admit non-Kerr black holes. Here, we use the black hole shadow to investigate the constraints when rotating regular black holes (non-Kerr) can be considered as astrophysical black hole candidates, paying attention to three leading regular black hole models with additional parameters g related to non-linear electrodynamics charge. Our interesting results based on the systematic bias analysis are that rotating regular black holes shadows may or may not capture Kerr black hole shadows, depending on the values of the parameter g . Indeed, the shadows of Bardeen black holes ($g \lesssim 0.26M$), Hayward black holes ($g \lesssim 0.65M$), and non-singular black holes ($g \lesssim 0.25M$) are indistinguishable from Kerr black hole shadows within the current observational uncertainties, and thereby they can be strong viable candidates for the astrophysical black holes. Whereas Bardeen black holes ($g \leq 0.30182M$), Hayward black holes ($g \leq 0.73627M$), and non-singular black holes ($g \leq 0.30461M$), within the 1σ region for $\theta_d = 39 \mu\text{as}$, are consistent with the observed angular diameter of M87*. This work has been done in collaboration with Rahul Kumar, and Amit Kumar.

Tuhin Ghosh

Detection of WHIM in the Planck data using Stack First approach

In this work, we detect the diffuse thermal Sunyaev-Zeldovich (tSZ) effect from the gas filaments between the Luminous Red Galaxy (LRG) pairs using a new approach relying on stacking the individual frequency maps. We apply and demonstrate our method on $\sim 88,000$ LRG pairs in the SDSS DR12 catalogue selected with an improved selection criterion that ensures minimal contamination by the Galactic CO emission as well as the tSZ signal from the clusters of galaxies. We first stack the Planck channel maps, and then perform the Internal Linear Combination method to extract the diffuse y_{sz} signal. Our Stack First approach makes the component separation a lot easier as the stacking greatly suppresses the noise and CMB contributions, while the dust foreground becomes homogeneous in spectral-domain across the stacked patch. Thus one component, the CMB, is removed while the rest of the foregrounds are made simpler even before component separation algorithm is applied. We obtain the WHIM signal of $y_{\text{whim}} = (3.78 \pm 0.37) \times 10^{-8}$ in the gas filaments, accounting for the electron overdensity of ~ 13 . We estimate the detection significance to be $\geq 10.2\sigma$. This excess y_{sz} signal is tracing the warm-hot intergalactic medium and it could account for most of the missing baryons of the Universe. We show that the Stack First approach is more robust to systematics, and produces a cleaner signal compared to the methods relying on stacking the y -maps to detect weak tSZ signal currently being used by the cosmology community. This work has been done in collaboration with Baibhav Sharma, and Rishi Khatri.

Dust polarization modeling at large-scale over the northern Galactic cap using EBHIS and Planck data

The primary source of systematic uncertainty in the quest for the B -mode polarization of the Cosmic Microwave Background (CMB) introduced by primordial gravitational waves is polarized thermal emission from Galactic dust. Therefore, accurate characterization and separation of the polarized thermal dust emission is an essential step in distinguishing such a faint CMB B -mode signal. We provide a modelling framework to simulate



polarized thermal dust emission based on the model described in Ghosh, et al. (2017), making use of both the Planck dust and Effelsberg-Bonn HI surveys over the northern Galactic cap. Our seven-parameter dust model, incorporating both HI gas in three different column density templates as a proxy for spatially variable dust intensity and a phenomenological model of Galactic magnetic field, is able to reproduce both 1- and 2-point statistics of the observed dust polarization maps seen by Planck at 353 GHz over a selected low-column density region in the northern Galactic cap. This work has important applications in assessing the accuracy of component separation methods and in quantifying the confidence level of separating polarized Galactic emission and the CMB B-mode signal, as is needed for ongoing and future CMB missions. This work has been done in collaboration with Debabrata Adak, Francois Boulanger, Urmaz Haud, Peter Kalberla, et al.

Umananda D. Goswami

A new $f(R)$ gravity model and properties of gravitational waves in it

In this work, we have introduced a new $f(R)$ gravity model as an attempt to have a model with more parametric control, so that the model can be used to explain the existing problems as well as to explore new directions in physics of gravity, by properly constraining it with recent observational data. In $f(R)$ gravity metric formalism, the model shows the existence of scalar degree of freedom as like other $f(R)$ gravity models. Due to this reason, there are two extra scalar modes of polarization of GWs present in the theory. These two extra polarization modes present in a mixed state, out of which one is transverse massless breathing mode with non-vanishing trace and the other is massive longitudinal mode. The longitudinal mode being massive, travels at speed less than the usual tensor modes found in General Relativity (GR). Moreover, for a better understanding of the model, we have studied the potential and mass of scalar graviton in both Jordan and Einstein Frames. This model can pass the solar system tests and can explain primordial and present dark energy. It is found that the correlation function for massive longitudinal mode of polarization under certain mass scale predicted by the model agrees well with the recent data of Pulsar Timing Arrays. It seems that

this new model would be useful in dealing with different existing issues in the areas of astrophysics and cosmology. This work has been done in collaboration with Dhruba J. Gogoi.

Radial oscillations and gravitational wave echoes of strange stars for various equations of state

We study the radial oscillations of non-rotating strange stars (SSs) and their characteristic echo frequencies for three equations of state (EoS), viz., MIT Bag model, linear, and polytropic. The frequencies of radial oscillations of these compact stars are computed for these EoSs. In total, 22 lowest radial frequencies for each of these three EoSs have been computed. First, for each EoS, we have integrated Tolman-Oppenheimer-Volkoff equations numerically to calculate the radial and pressure perturbations of SSs. Next, the mass-radius relationships for these stars are obtained using these three EoSs. Our numerical results show that the radial frequencies and also echo frequencies vastly depend on the model and on the value of the model parameter. Our results also show that the radial frequencies of strange stars are maximum for polytropic EoS in comparison to MIT Bag model EoS and linear EoS. Moreover, SSs with MIT Bag model EoS and linear EoS are found to emit gravitational wave echoes. Whereas, SSs with polytropic EoS are not emitting gravitational wave echoes. This work has been done in collaboration with Jyatsnasree Bora .

Shivappa B. Gudennavar

Estimation of the black hole spin in LMC X-1 using AstroSat

In this work, we report the results of simultaneous broadband spectral studies of LMC X-1 carried out using the data from Soft X-ray Telescope and Large Area X-ray Proportional Counter aboard *AstroSat*, observed on 2016 November 26, 2016 and 2017 August 28. The combined spectrum was modelled with a multi-colour blackbody emission (*diskbb*) along with a Comptonization component (*simpl*) in the energy range 0.7–30.0 keV. The spectral analysis revealed that the source was in its high soft state ($\Gamma = 2.67^{+0.24}_{-0.24}$ and $\Gamma = 2.12^{+0.19}_{-0.20}$) with a hot disc ($kT_{in} = 0.86^{+0.01}_{-0.01}$ and $kT_{in} = 0.87^{+0.02}_{-0.02}$). Thermal disc emission was fit with a relativistic model (*kerrbb*) and the spin of the black hole was estimated to be $0.93^{+0.01}_{-0.01}$ and $0.93^{+0.04}_{-0.03}$.



(statistical errors) for the two epochs through X-ray continuum-fitting, which agrees with the previous results. This work has been done in collaboration with Sneha P. Mudambi, Anjali Rao, Ranjeev Misra, and S.G. Bubbly

Sarbari Guha

On the gravitational entropy of accelerating black holes

In this study, we have examined the validity of a proposed definition of gravitational entropy in the context of accelerating black hole solutions of the Einstein field equations. We have adopted a phenomenological approach proposed in Rudjord, et al. [*Phys. Scr.* **77**, 055901 (2008)] and expanded by Romero, et al. [*Int. J. Theor. Phys.* **51**, 925 (2012)], in which the Weyl curvature hypothesis is tested against the expressions for the gravitational entropy. Considering the C-metric for the accelerating black holes, we have evaluated the gravitational entropy and the corresponding entropy density for four different types of black holes, namely, non-rotating black hole, non-rotating charged black hole, rotating black hole and rotating charged black hole. Finally, we discuss the merits of such an analysis, and the possible reason of failure in the particular case of rotating charged black hole and comment on the possible resolution of the problem. This study has been done in collaboration with Samarjit Chakraborty.

Axial gravitational waves in Bianchi I universe

In Regge-Wheeler gauge, there are only two non-zero components of $h_{\mu\nu}$ in the case of axial waves: $h_0(t, r)$ and $h_1(t, r)$. The field equations in absence of matter have been derived both for the unperturbed as well as axially perturbed metric. These field equations are solved simultaneously by assuming the expansion scalar Θ to be proportional to the shear scalar σ (so that $a = b^n$, where a, b , are the metric coefficients, and n is an arbitrary constant), and the wave equation for the perturbation parameter $h_0(t, r)$ has been derived. We used the method of separation of variables to solve for this parameter, and have subsequently determined $h_1(t, r)$. We find that the anisotropy of the background spacetime is responsible for the damping of the gravitational waves as they propagate. The perturbations depend on the values

of the angular momentum l . The field equations in the presence of matter reveal that the axially perturbed spacetime leads to perturbations only in the azimuthal velocity of the fluid leaving the matter field undisturbed. This work has been done in collaboration with Sucheta Datta.

Priya Hasan

Membership of stars in open clusters using random Forest with Gaia data

In this study, we used the published membership data of nine open star clusters as a training set to find new members from Gaia DR2 data using a supervised random Forest model with a precision of around 90%. The number of new members found is often double the published number. Membership probability of a larger sample of stars in clusters is a major benefit in determination of cluster parameters like distance, extinction and mass functions. We also found members in the outer regions of the cluster and found sub-structures in the clusters studied. The colour magnitude diagrams are more populated and enriched by the addition of new members making their study more promising. This study has been done in collaboration with Md. Mahmudunnobe, Mudasir Raja, and Syed N. Hasan.

The system of open star clusters revisited

The system of open clusters is an excellent probe of the structure and evolution of the galactic disk. Their spatial, size, age and mass distributions provide valuable information on the cluster formation process. This study is based on available catalogues, both homogeneous and inhomogeneous, to provide some useful insights on the evolutionary history of the system of open clusters and consequently, the galaxy. We find that the optimum size of a cluster for its survival is 3-4 pc. We also find that there exists a simple linear relationship between the age and the mean linear diameters of clusters and also with normalised reddening. Using Gaia DR2 and other catalogues, we find that the system of open clusters provides valuable clues to our understanding of the evolution of the galaxy. This system can be partitioned by k-means to get clusters in a statistical sense, which indicates possible cluster formation in the galaxy at different galacto-centric distances and with different parameters. These



suggests a combination of the scenarios of overall halo collapse and accretion to explain the formation of the disk of the galaxy. This method is proposed to be used for the study of external galaxies using catalogues of extragalactic clusters as it works well with the clusters of the Milky Way. This study has been done in collaboration with Syed N. Hasan.

Deepak Jain

Constraining cosmological and galaxy parameters using strong gravitational lensing systems

Strong gravitational lensing along with the distance sum rule method can constrain both cosmological parameters as well as density profiles of galaxies without assuming any fiducial cosmological model. To constrain galaxy parameters and cosmic curvature (Ω_{k0}), we use the distance ratio data from a recently compiled database of 161 galactic scale strong lensing systems. We use databases of supernovae type-Ia (Pantheon) and Gamma Ray Bursts (GRBs) for calculating the luminosity distance. To study the model of the lens galaxy, we consider a general lens model namely, the Extended Power-Law. Further, we take into account two different parameterisations of the mass density power-law index (γ) to study the dependence of (γ) on redshift. The best value of Ω_{k0} suggests a closed universe, though a flat universe is accommodated at 68% confidence level. We find that parameterisations of (γ) have a negligible impact on the best fit value of the cosmic curvature parameter. Furthermore, measurement of time delay can be a promising cosmographic probe via "time delay distance" that includes the ratio of distances between the observer, the lens and the source. We again use the distance sum rule method with time-delay distance dataset of H0LiCOW to put constraints on the Cosmic Distance Duality Relation (CDDR) and the cosmic curvature parameter (Ω_{k0}). For this we consider two different redshift-dependent parameterisations of the distance duality parameter (η). The best fit value of Ω_{k0} clearly indicates an open universe. However, a flat universe can be accommodated at 95% confidence level, at which, no violation of CDDR is observed. We believe that a larger sample of strong gravitational lensing systems is needed in order to improve the constraints on the cosmic curvature and distance duality parameter. This work has been done in collaboration with Darshan

Kumar, Shobhit Mahajan, Amitabha Mukherjee, and Nisha Rani

Deepak Jain and T. R. Seshadri

Impact of magnetic field on the gas mass fraction of galaxy clusters

Magnetic fields have been observed in galaxy clusters with strengths of the order of $\sim \mu\text{G}$. The non-thermal pressure exerted by magnetic fields also contributes to the total pressure in galaxy clusters and can in turn affect the estimates of the gas mass fraction, f_{gas} . In this work, we have considered a central magnetic field strength of $5 \mu\text{G}$, motivated by observations and simulations of galaxy clusters. The profile of the magnetic field has also been taken from the results obtained from simulations and observations. The role of magnetic field has been taken into account in inferring the gas density distribution through the hydrostatic equilibrium condition (HSE) by including the magnetic pressure. We have found that the resultant gas mass fraction is smaller with magnetic field as compared to that without magnetic field. However, this decrease is dependent on the strength and the profile of the magnetic field. We have also determined the total mass using the NFW profile to check for the dependency of f_{gas} estimates on total mass estimators. From our analysis, we conclude that for the magnetic field strength that galaxy clusters seem to possess, the non-thermal pressure from magnetic fields has an impact of $\approx 1\%$ on the gas mass fraction of galaxy clusters. However, with upcoming facilities like Square Kilometre Array (SKA), it can be further expected to improve with more precise observations of the magnetic field strength and profile in galaxy clusters, particularly in the interior region. This work has been done in collaboration with Sandhya Jagannathan, and Sunil Malik.

Jessy Jose

Testing the role of environmental effects on the initial mass function of low-mass stars

In the star formation process, the vital impact of environmental factors such as feedback from massive stars and stellar density on the form of the initial mass function (IMF) at low-mass end is yet to be understood. Hence, a systematic highly sensitive observational analysis of a sample



of regions under diverse environmental conditions is essential. We analyse the IMF of eight young clusters (<5 Myr), namely IC1848-West, IC1848-East, NGC 1893, NGC 2244, NGC 2362, NGC 6611, Stock 8 and Cygnus OB2, which are located at the galacto-centric distance (R_g) range ~ 6 -12 kpc along with nearby cluster IC348 using deep near-IR photometry and Gaia DR2. These clusters are embedded in massive stellar environments of radiation strength $\log(L_{FUV}/L_\odot) \sim 2.6$ to 6.8, $\log(L_{EUV}) \sim 42.2$ to 50.85 photons/s, with stellar density in the range of ~ 170 - 1220 stars/pc². After structural analysis and field decontamination, we obtain an unbiased, uniformly sensitive sample of pre-main-sequence members of the clusters down to brown-dwarf regime. The lognormal fit to the IMF of clusters give the mean characteristic mass (m_c) and σ of $0.32 \pm 0.02 M_\odot$ and 0.47 ± 0.02 , respectively. We compare the IMF with that of low- and high-mass clusters across the Milky Way. We also check for any systematic variation with respect to the radiation field strength, stellar density as well with R_g . We conclude that there is no strong evidence for environmental effect in the underlying form of the IMF of these clusters. This work has been done in collaboration with Belinda Damian, Manash R. Samal, Estella Mouraux, Swagat R. Das, et al.

Testing the star formation scaling relations in the clumps of the North American and Pelican nebulae cloud complex

We test various star formation scaling relations, such as the Kennicutt-Schmidt relation, the volumetric star formation relation, the orbital time model, the crossing time model and the multi free-fall time-scale model, towards the North American Nebula and Pelican Nebula and in the cold clumps associated with them. Measuring stellar mass from young stellar objects and gaseous mass from CO measurements, we estimate the mean Σ_{SFR} , the star formation rate per free-fall time and the star formation efficiency for clumps to be $1.5 M_\odot \text{ yr}^{-1} \text{ kpc}^{-2}$, 0.009 and 2.0 per cent respectively, while for the whole region covered by both nebulae (which we call the 'NAN' complex) the values are $0.6 M_\odot \text{ yr}^{-1} \text{ kpc}^{-2}$, 0.0003 and 1.6 per cent respectively. For the clumps, we notice that the observed properties are in line with the correlation obtained between Σ_{SFR} and Σ_{gas} , and between Σ_{SFR} and Σ_{gas} per free-fall time and

orbital time for Galactic clouds. At the same time, we do not observe any correlation with Σ_{gas} per crossing time and multi free-fall time. Even though we see correlations in the former cases, however, all models agree with each other within a factor of 0.5 dex. It is not possible to discriminate between these models because of the current uncertainties in the input observables. We also test the variation of Σ_{SFR} with the dense gas but, because of low statistics, a weak correlation is seen in our analysis. This work has been done in collaboration with Swagat R. Das, Manash R. Samal, Shaobo Zhang, and Neelam Panwar.

Mehedi Kalam

Does dark matter admixed pulsar exist ?

We have considered a two-fluid model assuming that the pulsars are made of ordinary matter admixed with dark matter. Contribution of dark matter comes from the fitting of the rotation curves of the SPARC sample of galaxies. We have investigated the dark matter based on the singular isothermal sphere (SIS) dark matter density profile in the galactic halo region. Considering this two-fluid model, we have studied the physical features of the pulsars present in different galaxy in details. Here, we compute the probable radii, compactness (u) and surface red-shift (Z_s) of the four pulsars namely: PSR J1748-2021B in NGC 6440B galaxy, PSR J1911-5958A in NGC 6752 galaxy, PSR B1802-07 in NGC 6539 galaxy, and PSR J1750-37A in NGC 6441 galaxy. This work has been done in collaboration with Sajahan Molla, and Bidisha Ghosh.

Possible existence of dark matter admixed pulsar

We have discussed the possible existence of the dark matter admixed pulsars, based on singular isothermal sphere density profile, located in dwarf as well as in massive spiral galaxies. We use the universal rotational curve dark matter density profile to get similar results for the pulsars in the Milky Way galaxy. These findings may be treated as a useful complement to the earlier findings. Hence, we may conclude that there is a high possibility of the existence of dark matter admixed pulsars in most of the galaxies. This work has been done in collaboration with Nilofar Rahman, and Sajahan Molla.



Sanjeev Kalita

Scalaron gravity near Sagittarius A: Investigation of spin of the black hole and observing requirements*

We apply the scalaron gravity field and corresponding Yukawa coupling (derived by Kalita from the consideration of quantum vacuum fluctuations with UV and IR scales) to examine the scales of stellar orbits near the Galactic Center black hole, which can be probed by upcoming astrometric facilities for constraining modified gravity. Through the assumption that the pericenter shift of stellar orbits becomes the order of spin and quadrupole moment effects of the black hole, it is found that for semi-major axes bounded below by time scales of gravitational wave emission and stellar age and above by S-2 like orbits ($a = 990$ au) the black hole spin with $0.1 \leq \chi \leq 0.980$ is eligible to probe scalaron masses within $(10^{-20} - 10^{-18})$ eV and also the scalaron coupling, $\alpha = 2.73 \times 10^{-4}$ derived earlier from quantum vacuum fluctuations. The orbital eccentricities are considered as $e = 0.1, 0.5$, and 0.9 . Astrometric categories with $\alpha = 10, 50$, and $100 \mu\text{as}$ are used to probe the time scales, and number of observing campaigns required for simultaneously constraining scalaron mass and black hole spin. It is found that extraction of black hole spin is possible within $a = (74-433)$ au through $10 \mu\text{as}$ facilities. The present analysis is realized to be an independent opportunity to simultaneously constrain scalaron coupling, black hole spin, and tidal charge, and hence to reveal the true nature of the spacetime structure of our nearest supermassive black hole.

The galactic centre black hole, Sgr A, as a probe of new gravitational physics with the scalaron fifth force*

The galactic centre black hole (Sgr A*) provides an ideal laboratory for astronomical tests of new gravitational physics. This work reports that curvature correction $f(R)$ to quantum vacuum fluctuations naturally yields a Yukawa-type scalar fifth force with potential $\exp(M_\psi r)/r$ where M_ψ is the mass of the $f(R)$ scalarons. Estimating the UV and IR cutoff scales of vacuum fluctuations, the Yukawa coupling strength is connected to the scalaron field amplitude. Whereas, recently constrained Yukawa coupling and range correspond to light scalarons with $M_\psi = (1.37 \times 10^{-21} - 5.49 \times 10^{-20})$ eV, vacuum fluctuations yield a massive

scalaron with $M_\psi = 10^{16}$ eV. Scalaron-induced periastron shift of stellar orbits near Sgr A* has been studied with respect to the semi-major axis in the range $a = 10-1,000$ au. It is found that the scalarons resulting from quantum fluctuations affect the precession of orbits with $a = 128-256$ Rs. The possibility of future constraints on massive scalarons in observations near Sgr A* is discussed. This is a new and independent effort to express a prototype quantum gravity effect in terms of astronomically accessible quantities.

Nishikanta Khandai

The distribution of neutral hydrogen in the colour-magnitude plane of galaxies

We present the conditional HI (neutral hydrogen) Mass Function (HIMF) conditioned on observed optical properties, M_r (r -band absolute magnitude) and C_{ur} ($u-r$ colour), for a sample of 7,709 galaxies from ALFALFA (40% data release - $\alpha.40$) which overlaps with a common volume in SDSS DR7. Based on the conditional HIMF, we find that the luminous red, luminous blue and faint blue populations dominate the total HIMF at the high-mass end, knee and the low-mass end respectively. We use the conditional HIMF to derive the underlying distribution function of Ω_{HI} (HI density parameter), $p(\Omega_{\text{HI}})$, in the colour-magnitude plane of galaxies. The distribution, $p(\Omega_{\text{HI}})$, peaks in the blue cloud at $M_r^{\text{max}} = -19.25$, $C_{ur}^{\text{max}} = 1.44$ but is skewed. It has a long tail towards faint blue galaxies and luminous red galaxies. We argue that $p(\Omega_{\text{HI}})$ can be used to reveal the underlying relation between cold gas, stellar mass, and the star formation rate (SFR) in an unbiased way; that is, the derived relation does not suffer from survey or sample selection. This work has been done in collaboration with Saili Dutta.

Ram Kishor

Effect of Moon perturbation on the energy curves and equilibrium points in the Sun-Earth-Moon system

In this work, we have considered that the Moon motion around the Earth is a source of a perturbation for the infinitesimal body motion in the Sun-Earth system. The perturbation effect is analyzed by using the Sun-Earth-Moon bicircular



model (BCM). We have determined the effect of this perturbation on the Lagrangian points and zero velocity curves. We have obtained the motion of infinitesimal body in the neighbourhood of the equivalent equilibria of the triangular equilibrium points. Moreover, to know the nature of the trajectory, we have estimated the first order Lyapunov characteristic exponents of the trajectory emanating from the vicinity of the triangular equilibrium point in the proposed system. It is noticed that due to the generated perturbation by the Moon motion, the results are affected significantly, and the Jacobian constant is fluctuated periodically as the Moon is moving around the Earth. Finally, we emphasize that this model could be applicable to send either satellite or telescope for deep space exploration. This work has been done in collaboration with Ashok K. Pal, and Elbaz I. Abouelmagd.

Nagendra Kumar

Mode conversion and damping of MHD waves in stratified viscous solar atmosphere

Acoustic waves generated by the convective motions in the solar convection zone undergo the mode conversion when they reach the height where the sound speed equals the Alfvén speed. Stratification-induced mode conversion depends on the strength of magnetic structures and so usually occurs in the upper atmosphere and chromosphere. We study the mode conversion and damping of MHD waves in a gravitationally stratified low- β to high- β isothermal atmosphere of the Sun permeated by a uniform vertical magnetic field. We solve the MHD equations by MacCormack method to examine the effect of viscosity on amplitudes of physical quantities such as velocity, mass density, gas pressure and magnetic field before and after the $\beta \approx 1$ layer. It is found that mode conversion occurs at the point $z \approx 1.8$ Mm in $\beta \approx 1$ layer and viscosity does not influence the mode conversion phenomenon. In the presence of viscosity, the amplitudes of vertical and horizontal velocity components, horizontal and vertical magnetic field components, gas pressure and mass density decrease, and decay of amplitude is stronger for higher values of viscosity. In the low β plasma, damping length decreases with the increase in viscosity but remains almost unchanged in the high β plasma. When the driving

frequency increases, conversion from slow to fast mode decreases. This work has been done in collaboration with Anil Kumar.

Sanjay Kumar

Magnetohydrodynamic simulation of magnetic null-point reconnections and coronal dimmings during the X2.1 flare in NOAA AR 11283

The magnetohydrodynamics of active region NOAA 11283 is simulated using an initial non-force-free magnetic field extrapolated from its photospheric vector magnetogram. We focus on the magnetic reconnections at a magnetic null point that participated in the X2.1 flare on 2011 September 6 around 22:21 UT (SOL2011-09-06T22:21X2.1) followed by the appearance of circular flare ribbons and coronal dimmings. The initial magnetic field from extrapolation displays a three-dimensional (3D) null topology overlying a sheared arcade. Prior to the flare, magnetic loops rise due to the initial Lorentz force, and reconnect at the 3D null, leading to expansion and loss of confined plasma that produce the observed pre-flare coronal dimmings. Further, the simulated dynamics documents the transfer of twist from the arcade to the overlying loops through reconnections, developing a flux rope. The non-parallel field lines comprising the rope and lower-lying arcades form an X-type geometry. Importantly, the simultaneous reconnections at the 3D null and the X-type geometry can explain the observed circular and parallel flare ribbons. Reconnections at the 3D null transform closed inner spine field lines into open field lines of the outer spine. The footpoints of these open field lines correspond to a ring-shaped coronal dimming region, tracing the dome. Further, the flux rope bifurcates because of these reconnections, which also results in the generation of open magnetic field lines. The plasma loss along the open field lines can potentially explain the observed coronal dimming. This work has been done in collaboration with Avijeet Prasad, Karin Dissauer, Qiang Hu, Ramit Bhattacharyya, et al.

Magnetic reconnections in the presence of three-dimensional magnetic nulls and quasi-separatrix layers

Three-dimensional (3D) magnetohydrodynamic simulations are carried out to explore magnetic



reconnections in the presence of 3D magnetic nulls and quasi-separatrix layers (QSLs). The initial magnetic fields are created by superposing uniform vertical magnetic fields of two different magnitudes on a linear force-free field. The interior of the numerical box contains two 3D nulls with separatrix domes separated by a quasi-separator (or hyperbolic flux tube) with QSLs. In the first simulation, the uniform vertical field is so large that the nulls are located at low heights and the domes are separate. Initially unbalanced Lorentz forces drive rotational flows that form strong electric currents and strong torsional fan reconnection at the 3D nulls and weak QSL reconnection at the hyperbolic flux tube. Flipping or slipping of field lines is observed in both cases. In the second simulation, with a weaker vertical field and larger domes, the separatrix surfaces meet at the central quasi-separator and their rotation drives stronger QSL reconnection than before. This work has been done in collaboration with Sushree S. Nayak, Avijeet Prasad, and Ramit Bhattacharyya.

R. K. Sunil Kumar

Linguistically involved data-driven approach for Malayalam phoneme-to-viseme mapping

Knowledge about the phonemes and visemes in the language is a vital component in the speech-based applications. A phoneme is the nuclear sound unit necessary to symbolize all words in that speech. The Present definition of viseme is a visual language unit that describes the state of different speech articulators. This article discusses the primary task of the identification of visemes and the number of frames required to encode the temporal evolution of vowel and consonant phonemes. For this work, an audio-visual Malayalam speech database is created from 23 native speakers of Kerala (18 females and five males). The tongue plays a vital role in the utterance of Malayalam, regarding flexibility and speed, which makes it distinct from other languages. The appearance of teeth and oral cavity and the shape of the lips can be modelled using geometric features of lips obtained from HSV colour space, and the deformation in the appearance of lips and tongue can be modelled using Discrete Cosine Transform (DCT) feature. A linguistically involved data-driven approach can make valuable individual perception modelling from a linguistic

approach and the computational easiness out of a data-driven approach. The visual speech attributes are then clustered to identify the visual equivalent of the phoneme employing K-means cluster and Gap statistic. To study the temporal variation, three phoneme-to-viseme mappings were analyzed, and are compared with the linguistic mapping and visual speech duration. This work has been done in collaboration with K. T. Bibish Kumar, Sunil John and K. M. Muraleedharan.

Data pre-processing techniques for handling time series data for environmental science studies

The errors or noises due to electronic sensor fault, fault in the communication channel, etc. are considered here. Such errors or glitches that occur during the data acquisition or transmission phases need to be eliminated before it is fed to the forecasting or classification, systems. Computationally, simple and efficient techniques, are discussed here so that they can even be adopted for a hard real time system environment. While adopting these techniques, we may also end up with some of the real genuine values which may consider as an outlier. A special indicator function, the moving Inter Quartile Range (MIQR) algorithm is proposed to overcome such special cases This work has been done in collaboration with Ebin Anthony, N.S. Sreekanth, and T. Nishanth.

S. Sunil Kumar

Evaporation of inclined drops: Formation of asymmetric ring patterns

Evaporation of colloidal drops on horizontal surfaces deposits the contained particles at the drop-edge producing radially symmetric ring-like stains. The symmetry in the particle deposition is broken when the drop is placed on a tilted surface due to the influence of gravity on the suspended particles and the drop itself. Using extremely small drops generated by electrospray, we explore cases where different mechanisms of particle transport dominate. We show that the asymmetric residues are formed as the gravity-induced effects compete with the capillary flow. Our results give a broad insight into the pattern formation of evaporating inclined drops. This work has been done in collaboration with Maheshwar Gopu, Sachin Rathod, Uma Namangalam, Ravi K. Pujala, et al.



Theoretical investigation of a vital step in the gas-phase formation of interstellar ammonia
 $NH_2^+ + H_2 \rightarrow NH_3^+ + H$

A crucial step in the gas-phase formation of ammonia in the interstellar medium (ISM) is the reaction of NH_2^+ with molecular hydrogen. Understanding the electronic structure of the participating species in this reaction, and the evaluation of the rate coefficients at interstellar temperatures are, therefore, critical to gain new insights into the mechanisms of formation of interstellar ammonia. We present the first theoretical results of the rate coefficients of this reaction as a function of temperatures relevant to the ISM, computed using transition-state theory. The results are in reasonable agreement with recent experimental data. This exothermic reaction features a tiny barrier, which is primarily a consequence of zero-point energy corrections. The results demonstrate that quantum mechanical tunneling and core-electron correlations play significant roles in determining the rate of the reaction. The noteworthy failure of popular density functionals to describe this reaction is also highlighted. This work has been done in collaboration with Salvi Mohandas, and Raghunath O. Ramabhardran.

Suresh Kumar

Measurements of H_0 and reconstruction of the dark energy properties from a model-independent joint analysis

Gaussian processes (GP) provide an elegant and model-independent method for extracting cosmological information from the observational data. In this work, we employ GP to perform a joint analysis by using the geometrical cosmological probes such as Supernova Type Ia (SN), Cosmic Chronometers (CC), Baryon Acoustic Oscillations (BAO), and the H0LiCOW lenses sample to constrain the Hubble constant H_0 , and reconstruct some properties of dark energy (DE), viz., the equation of state parameter w , the sound speed of DE perturbations c_s^2 , and the ratio of DE density evolution $X = \rho_{de}/\rho_{de,0}$. From the joint analysis SN+CC+BAO+H0LiCOW, we find that H_0 is constrained at 1.1% precision with $H_0 = 73.78 \pm 0.84 \text{ km s}^{-1} \text{ Mpc}^{-1}$, which is in agreement with SH0ES and H0LiCOW estimates, but in $\sim 6.2\sigma$ tension with the current CMB measurements

of H_0 . With regard to the DE parameters, we find $c_s^2 < 0$ at $\sim 2\sigma$ at high z , and the possibility of X to become negative for $z > 1.5$. We compare our results with the ones obtained in the literature, and discuss the consequences of our main results on the DE theoretical framework. This work has been done in collaboration with Alexander Bonilla, and Rafael C. Nunes.

Rastall gravity extension of the standard Λ CDM model: Theoretical features and observational constraints

We review the model for two simultaneous modifications of different nature in the Friedmann equation due to the Rastall gravity: The new contributions of the material (actual) sources (considered as effective source), and the altered evolution of the material sources. We discuss the role/behaviour of these modifications with regard to some low redshift tensions, including the so-called H_0 tension, prevailing within the standard Λ CDM. We constrain the model at the level of linear perturbations, and obtain the first constraints through a robust and accurate analysis using the latest full Planck Cosmic Microwave Background (CMB) data, with and without including Baryon Acoustic Oscillations (BAO) data. We find that the Rastall parameter ϵ (null for general relativity) is consistent with zero at 68% CL (with a tendency towards positive values, $-0.0001 < \epsilon < 0.0007$ (CMB+BAO) at 68% CL), which in turn implies no significant statistical evidence for deviation from general relativity, and also a precision of $\mathcal{O}(10^{-4})$ for the coefficient $-1/2$ of the term $g_{\mu\nu}R$ in the Einstein field equations of general relativity (guaranteeing the local energy-momentum conservation). We explore the consequences led by the Rastall gravity on the cosmological parameters in the light of the observational analyses. It turns out that the effective source, with a present-day density parameter $\Omega_{X0} = -0.0010 \pm 0.0013$ (CMB+BAO, 68% CL), dynamically screens the usual vacuum energy at high redshifts, but this mechanism barely works due to the opposition by the altered evolution of cold dark matter. Consequently, two simultaneous modifications of different nature in the Friedmann equation by the Rastall gravity act against each other, and do not help to considerably relax the low redshift tensions, including the so-called H_0 tension. Our results may offer a



guide for the research community that studies the Rastall gravity in various aspects of gravitation and cosmology. This work has been done in collaboration with Ozgur Akarsu, Nihan Kairci, Suresh Kumar, Rafael C. Nunes, et al.

Smriti Mahajan

Age and metallicity of galaxies in different environments of the Coma supercluster

We analyse luminosity-weighted ages and metallicity (Z) of galaxies in a continuous range of environments, i.e., clusters, filaments and voids prevalent in the Coma supercluster ($\sim 100h^{-1}$ Mpc). Specifically, we employ two absorption line indices, $H\beta$ and $\langle Fe \rangle$ as tracers of age and metallicity of galaxies. We find that the stellar-phase metallicity of galaxies declines with increasing age as a function of stellar mass (M^*) as well as environment. On the filaments, metallicity of galaxies varies as a function of their distance from the spine of the filament, such that galaxies closer to the centre of the filaments have lower metallicity relative to their counterparts 1 Mpc away from it. The mean age of intermediate mass galaxies ($10^{10} < M^*/M_\odot < 10^{10.5}$) is statistically significantly different in different environments such that, the galaxies in clusters are older than the filament galaxies by 1-1.5 Gyr, while their counterparts in the voids are younger than filament galaxies by ~ 1 Gyr. The massive galaxies ($M^*/M_\odot > 10^{10.5}$), on the other hand, show no such difference for the galaxies in clusters and filaments, but their counterparts in voids are found to be younger by ~ 0.5 Gyr. At fixed age, however, (Z) of galaxies is independent of their M^* in all environments, except the most massive ($M^*/M_\odot \gtrsim 10^{10.7}$), oldest galaxies ($\gtrsim 9$ Gyr), which show a sharp decline in their (Z) with M^* . Our results support a scenario where galaxies in the nearby Universe have grown by accreting smaller galaxies or primordial gas from the large-scale cosmic web. This work has been done in collaboration with Juhi Tiwari, and Kulinder P. Singh.

Study of galaxies on large-scale filaments in simulations

We use the data from the Evolution and Assembly of GaLaxies in their Environment (EAGLE) cosmological simulation to study properties of

galaxies in the cosmic web. Galaxies become more redder and form stars at a lower rate relative to their counterparts further away from the cylindrical axis of the large-scale filaments. These trends are particularly strong for galaxies with $M^*/M_\odot \lesssim 10^{10}$. We also find that at distances < 0.5 Mpc from the spine of the filaments, the median gas and stellar mass fraction in filament galaxies rises sharply with decreasing distance from the spine of the filament. These results, together with matching trends in the SFR/M_* and the $g-r$ colour of filament galaxies suggest that (i) the intrafilamentary gas condenses into the filament galaxies, thus, fuelling star formation in them, and (ii) increased number density of galaxies closer to the central axis of the filament enhances the rate of gravitational interactions among filament galaxies closer to the spine. This work has been done in collaboration with Ankit Singh, and Jasjeet S. Bagla.

Manzoor A. Malik

X-ray study of galaxy clusters

We present a detailed study of the excess entropy profiles along with feedback energy profiles, and discuss the effect of non-thermal pressure and clumping on our estimates with the XMM-Newton cluster outskirts project (X-COP), so as to understand the physical conditions in the outer regions of galaxy clusters ($R > R_{500}$). X-COP targets a sample of massive nearby clusters selected on the basis of their high signal-to-noise ratio (SNR) in the Planck all-sky survey of Sunyaev-Zeldovich sources. In the recent years, the progress achieved in the sensitivity of SZ instruments has allowed the extension of the measurements of the pressure profile of galaxy clusters out to the virial radius and beyond. The high SNR in the Planck survey ensures a detection of the SZ effect from targets well beyond R_{500} . X-COP provides a uniform 25 ks mapping of these clusters out to R_{200} and beyond, with the aim of combining high-quality X-ray and SZ imaging throughout the entire volume of these systems. Our objective is to study the entropy as a function of gas mass. In order to calculate the initial entropy profile as a function of gas mass, we use the initial radial entropy profile, in conjunction with the assumption of hydrostatic equilibrium. While non-thermal pressure is small in the inner



region, its relative importance steadily increases with radius, becoming a significant fraction of the total pressure in the outer region. It has been found from both observations and simulations that m_{500} is underestimated by about 10–20 per cent, if one uses the hydrostatic equation without non-thermal pressure. This work has been done in collaboration with Subha Majumdar, and Shahnawaz Malik .

Generation, propagation and detection of atmospheric gravity waves

On a different plane, we have detected some interesting ionospheric phenomena that include (i) Medium Scale Travelling Ionospheric Disturbance (MSTID), (ii) Field aligned plasma irregularities, (iii) Concentric ring like gravity waves, and (iv) Influences of subtropical mesospheric gravity waves on F-region Ionosphere and related phenomena like propagation and other space phenomena.

I. Ablu Meitei

Quantum radiation of Kerr black hole in de Sitter background

We investigate the tunneling of vector Boson particles across the event horizon of Kerr-de Sitter black hole by using Hamilton-Jacobi ansatz to Proca equation and WKB approximation. The surface gravity of KdS black hole has been recovered by using direct calculation and Proca equation. These two different methods give the same Hawking temperature at the event horizon. This work has been done in collaboration with T. Ibungochouba Singh, Y. Kenedy Meitei, and K. Yugindro Singh.

GUP effects on Hawking temperature in Riemann spacetime

The modified Hawking temperature of a static Riemann space-time is studied using the generalized Klein-Gordon equation and the generalized Dirac equation. Applying the Kerner-Mann quantum tunneling method, the modified Hawking temperatures for scalar particles and Fermions that cross the event horizon of the black hole have been derived. We observe that the quantum gravity effects reduce the rise of thermal radiation temperature of the black hole. This work has been done in collaboration with Y. Kenedy Meitei, and T. Ibungochouba Singh.

Hameeda Mir

Partition function and coherent states for the quantum multiverse

Motivated by a wider acceptance of the quantum cosmology and the idea of multiverse, we follow the second and third quantization formalism for the conceptual comprehension of quantum multiverse. The other motivating feature to pursue the present study is that at the different levels of quantization, the equation of quantum state is similar to that of harmonic oscillator, which encourages us to give a glancing taste of the coherent states in the domain of quantum cosmology. Third quantization enables one to model the universe as a particle in a quantum field theory of the mini-superspace, and the wave description prompts one to recognize interactions among the universes of the multiverse. This picture of the system further instigates us to investigate the partition function and the thermodynamic equations of the system. The path integral formalism with proper mathematical extensions are employed to find the partition function followed by the usual techniques of statistical mechanics to examine the thermodynamic properties. This work has been done in collaboration with Mario C. Rocca, and Aram B. Brzo.

Two approaches that prove divergence free nature of non-local gravity

This work is an attempt to study the thermodynamics of the structure formation in the large scale universe in the non-local gravity using Boltzmann statistics and the Tsallis statistics. The partition function is obtained in both the approaches, and the corresponding thermodynamics properties are evaluated. The important thing is that we surprisingly get the divergence free integrals, and thus, stress upon the fact that the non-local gravity is the singularity free model of gravity. This study has been done in collaboration with Behnan Pourhassan, and Mario C. Rocca.

Bivudutta Mishra

Stability analysis of two-fluid dark energy models

We have studied the stability of the cosmological models with dark energy, and combination of matter fields and dark energy in an anisotropic



space time. The pressure anisotropy along the spatial directions are derived and its stability in each direction has been examined. The four models presented here, show its stability on certain spatial direction. The role of matter field on the stability analysis has been obtained. The positive and negative value of cosmic string completely changed the stability behaviour of the model. The presence of a magnetic field disturbs the stability aspects of the models at least in an early epoch. This work has been done in collaboration with Fakhreh Md Esmaeili, Pratik P. Ray, and Sunil K. Tripathy.

Cosmological models with squared trace in modified gravity.

In this work, we present a few simple cosmological models under the modified theory of gravity in the particular form of $f(R, T) = R + 2f(T)$, where R is the Ricci scalar and T is the trace of the energy momentum tensor. Two special cosmological models are studied with (i) hyperbolic scale factor, and (ii) specific form of the Hubble parameter. The models are observed to predict relevant cosmological parameters closer to the observational values. Both the models reduce to overlap with the Λ CDM model at late times. We have discussed some interesting results related to wormhole solutions as evolved. The possible occurrence of Big Trip in wormholes for the models are also discussed. This work has been done in collaboration with Sunil K. Tripathy, and Saibal Ray.

Sourav Mitra

Dark matter annihilation in ω Centauri: Astrophysical implications derived from the MWA radio data

We present an analysis of Murchison Widefield Array radio telescope data from ω Cen, possibly a stripped dwarf spheroidal galaxy core captured by our Galaxy. Recent interpretations of Fermi-LAT γ -ray data by Brown, et al. (2019) and Reynoso-Cordova, et al. (2019) suggest that ω Cen may contain significant dark matter. We utilize their best-fit dark matter annihilation models, and an estimate of the magnetic field strength in ω Cen, to calculate the expected radio synchrotron signal from annihilation, and show that one can usefully rule out significant parts of the magnetic field diffusion coefficient plane using our

current observational limits on the radio emission. Improvement by a factor of 10-100 on these limits could constrain the models even more tightly. This work has been done in collaboration with Arpan Kar, Biswarup Mukhopadhyaya, Steven Tingay, Ben McKinley, et al.

Hybrid analytic and machine-learned baryonic property insertion into galactic dark matter haloes

While cosmological dark matter-only simulations relying solely on gravitational effects are comparably fast to compute, baryonic properties in simulated galaxies require complex hydrodynamic simulations that are computationally costly to run. We explore the merging of an extended version of the equilibrium model, an analytic formalism describing the evolution of the stellar, gas, and metal content of galaxies, into a machine learning framework. In doing so, we are able to recover more properties than the analytic formalism alone can provide, creating a high-speed hydrodynamic simulation emulator that populates galactic dark matter haloes in N-body simulations with baryonic properties. While, there exists a trade-off between the reached accuracy and the speed advantage, this approach offers, our results outperform an approach using only machine learning for a subset of baryonic properties. We demonstrate that this novel hybrid system enables the fast completion of dark matter-only information by mimicking the properties of a full hydrodynamic suite to a reasonable degree, and discuss the advantages and disadvantages of hybrid versus machine learning-only frameworks. In doing so, we offer an acceleration of commonly deployed simulations in cosmology. This work has been done in collaboration with Ben Moews, Romeel Dave, Sultan Hassan, and Weiguang Cui.

Aditya S. Mondal and Biplab Raychaudhuri

On the disc reflection spectroscopy of NS LMXB Serpens X-1: Analysis of a recent nustar observation

We present nustar observation of the atoll type neutron star (NS) low-mass X-ray binary (LMXB) Serpens X-1 (Ser X-1) performed on 17 February 2018. We observed Ser X-1 in a soft X-ray spectral state with 3 – 79 keV luminosity of $L_X \sim 0.4 \times 10^{38}$ erg s⁻¹ ($\sim 23\%$ of the Eddington luminosity),



assuming a distance of 7.7 kpc. A positive correlation between intensity and hardness ratio suggests that the source was in the banana branch during this observation. The broadband 3 – 30 keV *nustar* energy spectrum can be well described either by a three-component continuum model consisting of a disk blackbody, a single temperature blackbody and a power-law or by a two-component continuum model consisting of a disk blackbody and a Comptonization component. A broad iron line $\sim 5 - 8$ keV and the Compton back-scattering hump peaking at $\sim 10 - 20$ keV band are clearly detected in the X-ray spectrum. These features are best interpreted by a self-consistent relativistic reflection model. Fits with relativistically blurred disc reflection model suggests that the inner disc radius R_{in} is truncated prior to the ISCO at $(1.9 - 2.5) R_{ISCO}$ ($\simeq 11.4 - 15 R_g$ or $26 - 34$ km) and the accretion disc is viewed at an low inclination of $i \simeq 16^\circ - 20^\circ$. The disc is likely to be truncated either by a boundary layer or by the magnetosphere. Based on the measured flux and the mass accretion rate, the maximum radial extension for the boundary layer is estimated to be $\sim 6.4 R_g$ from the NS surface. The truncated inner disc in association with pressure from a magnetic field sets an upper limit of $B \leq 1.9 \times 10^9$ G. This observation has been done in collaboration with Gulab C. Dewangan

Evidence of disc reflection in the X-ray spectrum of the neutron star low-mass X-ray binary 4U 1636-536

We present a broadband spectral analysis of the atoll source 4U 1636-536 observed for ~ 92 ks with *nustar*. The source was found to be in a low-luminosity state during this observation with 3 – 79 keV X-ray luminosity of $L_{3-79\text{keV}} = (1.03 \pm 0.01) \times 10^{37}$ ergs/s, assuming a distance of 6 kpc. We have identified and removed twelve type-I X-ray bursts during this observation to study the persistent emission. The continuum is well described by a thermal Comptonization model `nthcomp` with $\Gamma \sim 1.9$, $kT_e \sim 28\text{keV}$, and $kT_s \sim 0.9\text{keV}$. The NuSTAR data reveal a clear signature of disc reflection, a significantly broad Fe-K emission line (around 5 – 8 keV), and the corresponding reflection hump (around 15 – 30 keV). We have modelled the data with two relativistically blurred reflection models. Both families of reflection models prefer truncated inner

disc radii prior to the ISCO. We find that the inner disc is truncated with an inner radius of $R_{in} = (3.2 - 4.7) R_{ISCO}$ ($\simeq 16 - 24 R_g$ or $36 - 54$ km). This inner disc radius suggests that the neutron star magnetic field strength is $B \leq 2.0 \times 10^9$ G. This observation has been done in collaboration with Gulab C. Dewangan

Soumen Mondal and Prasad Basu

On the properties of dissipative shocks in the relativistic accretion flows

In this work, we study the properties of dissipative shocks for fully relativistic accretion flows around spinning black holes. In an accretion flow harbouring a dissipative shock (formally known as radiative shock), a significant portion of the thermal energy may get released from the post-shock corona. A stellar-mass black hole may therefore emit hard X-rays from the inner edge of the disc. If the bulk energy loss is significant, post-shock pressure drops, and shock moves forward towards the black hole compressing the size of the post-shock corona, resulting an enhancement of the corona temperature and compression ratio. The dynamical properties of the radiative shocks are therefore systematically investigated to understand accurately the radiative loss processes, temporal variations, and the spectral properties. We notice that the range of flow parameters (e.g. energy and angular momentum) responsible for the formation of shocks in accretion (SA) is identical for both the cases of standing and dissipative shocks. The spin of the black hole enhances the dissipation further. We estimate the maximum energy release, which is observed close to 100 per cent in the extreme cases. This could be useful in explaining various observed phenomena namely the formation and the systematic evolution of quasi-periodic oscillations, and the time lags in between hard and soft X-ray photons (e.g. XTE J1550-564, GRO J1655-40, etc.) during their outbursts.

Soumen Mondal

FIRST winged radio galaxies with X and Z symmetry

X-shaped radio galaxies (XRGs) are a subclass of radio sources that exhibit a pair of secondary low surface brightness radio lobes oriented at



an angle to the primary high surface brightness lobes. Sometimes, they emerge from the edges of the primary high brightened lobes and form a Z-symmetric morphology. We present a systematical search result for XRGs and Z-shaped radio galaxies (ZRGs) from the VLA faint images of the radio sky at twenty-centimeters (VLA FIRST) survey at 1.4 GHz. Our search yields a total of 296 radio sources, out of which 161 are XRGs and 135 are ZRGs. We have also made optical identification of these sources from the different available literature. J1124+4325 and J1319+0502 are the farthest known XRG and ZRG, respectively. We have estimated spectral index and radio luminosity of these radio sources and made a comparative study with previously detected XRGs and ZRGs. The average value of luminosities for XRGs is higher than that of ZRGs. With the help of a large sample size of the newly discovered XRGs and ZRGs, various statistical properties of these sources are studied. Out of 161 XRGs presented, 70% (113) are FR II radio galaxies and 13% (20) are FR I radio galaxies. For 28 XRGs, the morphology is complex and could not be classified. For XRGs, the statistical studies are done on the angle between the major and minor axes and the relative size of these axes. For the ZRGs, a statistical study is done on the angular size. This work has been done in collaboration with Soumen Bera, Sabyasachi Pal, and Tapan K. Sasmal.

Hemwati Nandan

Particle collisions near static spherically symmetric black holes

It has been shown by Bañados, Silk and West (BSW) that the centre of mass energy (E_{cm}) of test particles starting from rest at infinity, and colliding near the horizon of a Schwarzschild black hole is always finite. In this note, we extend the BSW scenario and study two particles with different energies colliding near the horizon of a static spherically symmetric black hole. Interestingly, we find that even for the static spherically symmetric (i.e., Schwarzschild like) black holes, it is possible to obtain an arbitrarily high E_{cm} from the two test particles colliding near but outside of the horizon of a black hole, if one fine-tunes the parameters of geodesic motion. This work has been done in collaboration with Eva Hackmann, and Pankaj

Sheoran.

Schwarzschild black hole surrounded by quintessential matter field as an accelerator for spinning particles

We study the collision of two massive particles with non-zero intrinsic spin moving in the equatorial plane in the background of a Schwarzschild black hole surrounded by quintessential matter field (SBHQ). For the quintessential matter equation of state (EOS) parameter, we assume three different values. It is shown that for collisions outside the event horizon, but very close to it, the centre-of-mass energy (E_{cm}) can grow without bound if exactly one of the colliding particles is what we call near-critical, i.e., if its constants of motion are fine tuned such that the time component of its four-momentum becomes very small at the horizon. In all other cases, E_{cm} only diverges behind the horizon if we respect the Møller limit on the spin of the particles. We also discuss radial turning points and constraints resulting from the requirement of sub-luminal motion of the spinning particles. This work has been done in collaboration with Pankaj Sheoran, Eva Hackmann, Ulises Nucamendi, and Amare Abebe.

Rajesh K. Nayak

Implementation of the dual foliation generalized harmonic gauge formulation with application to spherical black hole excision

The formalism promises to give greater freedom in the choice of coordinates that can be used in numerical relativity. As a specific application, we focus on the treatment of black holes in spherical symmetry. Existing approaches to black hole excision in numerical relativity are susceptible to failure if the boundary fails to remain outflow. Our approach relies on carefully choosing coordinates in which the coordinate light speeds are under strict control so that the excision boundary must remain outflow. These coordinates are then combined with the DF-GHG formulation. After performing a set of validation tests in a simple setting, we study the accretion of large pulses of scalar field matter on to a spherical black hole. We compare the results of DF-excision with a naive setup. DF-excision proves reliable even when the previous approach fails. This work has been done in collaboration



with Maitraya K. Bhattacharyya, David Hilditch, Sarah Renkhoff, Hannes R. Ruter, et al.

Analytical and numerical treatment of perturbed black holes in horizon-penetrating coordinates

The deviations of non-linear perturbations of black holes from the linear case are important in the context of ringdown signals with large signal-to-noise ratio. To facilitate a comparison between the two, we derive several results of linear perturbation theory in coordinates which may be adopted in numerical work. Specifically, our results are derived in Kerr-Schild coordinates adjusted by a general height function. In the first part, we address the questions: For an initial configuration of a massless scalar field, what is the amplitude of the excited quasinormal mode (QNM) for any observer outside the event horizon, and furthermore, what is the resulting tail contribution? This is done by constructing the full Greens function for the problem with exact solutions of the confluent Heun equation satisfying appropriate boundary conditions. In the second part, we detail new developments to our pseudo-spectral numerical relativity code bumps to handle scalar fields. In the linear regime, we employ precisely the Kerr-Schild coordinates treated by our previous analysis. In particular, we evolve pure QNM type initial data along with several other types of initial data and report on the presence of overtone modes in the signal. This work has been done in collaboration with Maitraya K. Bhattacharyya, David Hilditch, Hannes R. Ruter, and Bernd Bruggmann.

Biswajit Pandey

Do galactic bars depend on environment?: An information theoretic analysis of Galaxy Zoo 2

We use an information theoretic framework to analyze data from the Galaxy Zoo 2 project and study if there are any statistically significant correlations between the presence of bars in spiral galaxies and their environment. We measure the mutual information between the barredness of galaxies and their environments in a volume limited sample ($M_r \leq -21$), and compare it with the same in datasets where (i) the bar/unbar classifications are randomized, and (ii) the spatial distribution of galaxies are shuffled on different length scales. We assess the statistical significance

of the differences in the mutual information using a t-test, and find that both randomization of morphological classifications and shuffling of spatial distribution do not alter the mutual information in a statistically significant way. The non-zero mutual information between barredness and environment arises due to the finite and discrete nature of the dataset, which can be entirely explained by mock Poisson distributions. We also separately compare the cumulative distribution functions of the barred and unbarred galaxies as a function of their local density. Using a Kolmogorov-Smirnov test, we find that the null hypothesis can not be rejected even at 75% confidence level. Our analysis indicates that environments do not play a significant role in the formation of a bar, which is largely determined by the internal processes of the host galaxy. This study has been done in collaboration with Suman Sarkar, and Snehasish Bhattacharjee.

A method for classification of red, blue and green galaxies using fuzzy set theory

The red and blue galaxies are traditionally classified using some specific cuts in colour or other galaxy properties, which are supported by empirical arguments. The vagueness associated with such cuts are likely to introduce a significant contamination in these samples. Fuzzy sets are vague boundary, which can efficiently capture the classification uncertainty in the absence of any precise boundary. We propose a method for classification of galaxies according to their colours using fuzzy set theory. We use data from the SDSS to construct a fuzzy set for red galaxies with its members having different degrees of 'redness'. We show that the fuzzy sets for the blue and green galaxies can be obtained from it using different fuzzy operations. We also explore the possibility of using fuzzy relation to study the relationship between different galaxy properties and discuss its strengths and limitations.

Mahadev B. Pandge

Exploring the hot gaseous halo around an extremely massive and relativistic jet launching spiral galaxy with XMM-Newton

We present a deep XMM-Newton observation of the extremely massive, rapidly rotating, relativistic-jet-launching spiral galaxy 2MASX



J23453268-0449256. Diffuse X-ray emission from the hot gaseous halo around the galaxy is robustly detected out to a radius of 160 kpc, corresponding roughly to 35 per cent of the virial radius (450 kpc). We fit the X-ray emission with the standard isothermal β model, and it is found that the enclosed gas mass within 160 kpc is $1.15^{+0.22}_{-0.24} \times 10^{11} M_{\odot}$. Extrapolating the gas mass profile out to the virial radius, the estimated gas mass is $8.25^{+1.62}_{-1.77} \times 10^{11} M_{\odot}$, which makes up roughly 65 per cent of the total baryon mass content of the galaxy. When the stellar mass is considered and accounting for the statistical and systematic uncertainties, the baryon mass fraction within the virial radius is $0.121^{+0.043}_{-0.043}$, in agreement with the universal baryon fraction. The baryon mass fraction is consistent with all baryons falling within r200, or with only half of the baryons falling within r200. Similar to the massive spiral galaxies NGC 1961 and NGC 6753, we find a low value for the metal abundance of $0.1 M_{\odot}$, which appears uniform with radius. We also detect diffuse X-ray emission associated with the northern and southern lobes, possibly attributed to inverse Compton scattering of Cosmic Microwave Background photons. The estimated energy densities of the electrons and magnetic field in these radio lobes suggest that they are electron-dominated by a factor of 10-200, depending on the choice of the lower cut-off energy of the electron spectrum. This work has been done in collaboration with Mohammad S. Mirakhor, Stephen A. Walker, Joydeep Bagchi, Pratik Dabhade, et al.

A detailed study of X-ray cavities in the intracluster environment of the cool core cluster Abell 3017

We present a detailed analysis of a cool-core galaxy cluster Abell 3017, at a redshift of $z = 0.219$, which has been identified to be merging with its companion cluster Abell 3016. This study has made use of X-ray (*Chandra*), UV (*GALEX*), optical (*ESO/VLT*), mid-infrared (*WISE*) and radio uGMRT observations. Using various image processing techniques, such as unsharp masking, 2-d fits using Beta models, contour binning and the use of surface brightness profiles, we show the existence of a pair of X-ray cavities, at a projected distance of ~ 20 arcsec (70 kpc) and ~ 16 arcsec (57 kpc), respectively from the core of Abell 3017. We also detect an excess of X-ray emission located at 25 arcsec (~ 88 kpc) south of the centre of

Abell 3017, is likely due to the bulk motions in the ICM, either by gas sloshing or ram-pressure striping due to a merger. We find that the radio lobes are responsible for the observed X-ray cavities detected in this system. The lower values of mid-IR WISE colour [W1-W2] and [W2-W3] imply that the central BCG of Abell 3017 is a star-forming galaxy. The current star formation rate of the central BCG, estimated from the $H\alpha$ and *GALEX* FUV luminosities, are equal to be $\sim 5.06 \pm 0.78 M_{\odot} yr^{-1}$ and $\sim 9.20 \pm 0.81 M_{\odot} yr^{-1}$, respectively. We detect, for the first time, a radio phoenix ~ 150 kpc away from the radio core, with a spectral index of ($\alpha \leq -1.8$). We also report the detection of Pa_{α} emission in this cluster using ESO VLT SINFONI imaging data. This work has been done in collaboration with Biny Sebastian, Ruchika Seth, and Somak Raychaudhury.

Uma Papnoi

Thermodynamics from field equations for charged radiating rotating black hole near horizon

It is well known that near horizon black hole spacetimes, show a resemblance to thermodynamic systems, it is easy to associate the thermodynamic parameters like temperature and entropy with them. We study the connection between gravitational dynamics of the horizon and thermodynamics for the case of charged radiating rotating axially symmetric black holes. It is shown that Einstein field equation near apparent horizon can be interpreted in the form of thermodynamic law, i.e., $TdS = dM(v) - \Omega_H dJ - \Phi dQ(v)$. This work has been done in collaboration with Sushant G. Ghosh.

Amit Pathak

Synthesis, structural and vibrational spectroscopic investigation of molecules: N-n-butyl, S-2-nitro-1-phenylethyl dithiocarbamate and N-n-butyl, S-2-nitro-1-(4-uropenyl) ethyl dithiocarbamate

This work deals with the synthesis as well as molecular modelling and vibrational spectroscopic analysis of two biorelevant molecules, namely N-n-butyl, S-2-nitro-1-phenylethyl dithiocarbamate and N-n-butyl, S-2-nitro-1-(4-fluorophenyl) ethyldithiocarbamate in gas phase. The optimization of the molecular



structures of these compounds was performed at Density Functional Theory with exchange functional B3LYP and Hartree-Fock theory. The customary basis set 6-31++G(d,p) was employed during computations at both the level. The experimental FTIR spectra of both the compounds were recorded in range 4,000-400 cm^{-1} to correlate with the calculated spectra of the compounds. The normal coordinate analysis (NCA) method was used for the calculation of potential energy distributions. Most of the DFT calculated frequencies were found to agree with the experimental FTIR frequencies. To ensure the stability of electronic structures of these compounds, the natural bond orbital analysis (NBO) for each compound was also performed and the analysis revealed that the intra-molecular interactions resulting from overlapping of bonding and anti-bonding orbitals provoke the intra-molecular charge transfer (ICT) causing stabilization of the system. The frontier bond orbital analysis was also performed to study the interaction profile of the compounds. This work has been done in collaboration with Tarun Yadav, Goutam Brahmachari, Indrajit Karmakar, Priyanka Yadav, et al.

Structural confirmation of biorelevant molecule N-iso-butyl, S-2-nitro-1-phenylethyl dithiocarbamate in gas phase and effect of fluorination

We have found a total of five low lying energy structures of N-iso-butyl, S-2-nitro-1-phenylethyl dithiocarbamate in the present investigation. All the theoretical computations were done at DFT/B3LYP/6-31++G(d,p) level. The FTIR spectrum of this molecule was recorded in the spectral range of 4,000-400 cm^{-1} , and this correlates well with the theoretical spectra of energetically most preferred conformer. The effect of fluorination on the structural parameters and vibrational frequencies of the most stable conformer is also investigated. The normal coordinate analysis was employed to calculate the potential energy distributions of the most stable conformer and the fluorinated structure. Moreover, we have also performed the natural bond orbital analysis (NBO) for the most stable conformer and the fluorinated structure to corroborate the stability of the electronic structure of both the molecules. The different thermodynamical quantities viz entropy,

specific heat, free energy and thermal energy are also investigated. This investigation has been done in collaboration with Tarun Yadav, Goutam Brahmachari, Indrajit Karmakar, Priyanka Yadav, et al.

Bikash C. Paul

Renyi holographic dark energy in higher dimension Cosmology

It is found that the non-interacting cosmological model naturally leads to the late accelerated universe, unlike the standard Holographic Dark Energy models in the usual 4-dimensions, however, it requires interaction to accommodate the late-time acceleration of the universe. The interacting model produces an accelerating universe at late time albeit failing to attain the estimated present value of the deceleration parameter. The evolution of different cosmological parameters have been estimated. We consider two diagnostic tests namely, state-finder and Om diagnostics proposed by Sahni to study the non-interacting model, which is more favoured in the light of recent cosmological observations. Classical stability of the cosmological models are also discussed. This work has been done in collaboration Arindam Saha, Souvik Ghose, and Anirban Chanda.

Bouncing scenario with causal cosmology

The cosmological model of a bouncing universe with causal fluid in the universe is presented. The dissipative effects of the causal cosmic fluid is described by the truncated, and full Israel-Stewart theory. The following classes of non-vanishing scale factors of bouncing cosmological solutions are considered in the presence of viscous fluid: (i) the power-law bouncing model, (ii) the exponential bouncing model, and (iii) the matter bouncing model in the Einstein gravity to study the dynamics of the early universe. The cosmological parameters namely, the Hubble parameter, deceleration parameter, jerk parameter in addition to the energy density and bulk viscous pressure of the universe are determined to construct realistic cosmologies. The observational constraints of the parameters of bouncing cosmological models are estimated making use of the observed cosmological data. The physical and geometrical aspects of the cosmological models based on the imposed



constraints are also estimated. This work has been done in collaboration with Partha S. Debnath.

Surajit Paul

uGMRT HI 21-cm absorption observations of two extremely inverted spectrum sources

We report the detection of HI 21-cm absorption in a member of the rare and recently discovered class of compact radio sources, 'Extremely Inverted Spectrum Extragalactic Radio Sources (EISERS)'. EISERS conceivably form a special sub-class of the inverted spectrum radio galaxies since the spectral index of the optically thick part of the spectrum for these sources crosses the synchrotron self absorption limit of $\alpha = +2.5$ ($S(\nu) \propto \nu^\alpha$). We have searched for HI absorption in two EISERS using the recently upgraded Giant Metrewave Radio Telescope (uGMRT) and detected an absorption feature in one of them. The strong associated HI absorption detected against the source J12092032 ($z=0.4040$) implies an optical depth of 0.178 ± 0.02 corresponding to an HI column density of $34.8 \pm 2.9 \times 10^{20} \text{ cm}^{-2}$, for an assumed HI spin temperature of 100 K and covering factor of 1. This is among the highest known optical depth and HI column densities found for compact radio sources of GPC/CSS type and supports the free-free absorption model for the steeply inverted radio spectrum of this source. For the other source, J1549+5038 ($z = 2.171$), no HI absorption was detected in our observations. This work has been done in collaboration with Mukul Mhaskey, Neeraj Gupta, Dipanjan Mukherjee, and Gopal-Krishna

Ninan S. Philip

Deconvolution of astronomical images

Ground based telescope images gets distorted by fluctuations in the atmosphere. Two possibilities exist to somewhat resolve this situation (i) Use machine learning tools to learn how a ground based image of a celestial object should be modified to look like its space telescope image. Once learned, the tool will be able to do similar transformation on all images taken in similar settings by ground based telescopes. (ii) Design an Adaptive Optics (AO) algorithm that can synchronise the mirror orientations with the atmospheric fluctuations so as to nullify the effect of the atmosphere. We have been working on a deep learning model

using Generative Adversarial Networks (GAN) for mapping ground based images taken by ZTF survey to space telescope images taken by Hubble. The deep learning AO algorithm is desired to perform faster than existing methods to control the actuators used in large AO driven telescopes. The first phase of development used noise free sky simulation and the performance of the algorithm was exceptional. However, when random Poison noise was added, the performance degraded drastically. We are trying to quantify the SNR to which similar methods might perform better than existing methods for AO. This work has been done in collaboration with Ajit K. Kembhavi, Kaushal Sharma, A. N. Ramaprabhakar, Sorabh Chhabra, et al.

NLP for fake domain identification

Natural Language Processing (NLP) finds lot of application in the bigdata era. However, the challenges are also not negligible. When information is on the network, validating genuine sources becomes a real challenge. There are a set of tools commonly known as Domain Generation Algorithms (DGA) that fake real domain names with hacker controlled sites. Detecting and isolating such fake sources is a big challenge. We at airis4D have developed an NLP algorithm that could detect and alert users by training a machine learning algorithm on known DGA and non-DGA domain names. DGA names are usually generated by software, and hence, are mostly combinations of random words or letters. This was the key identification criteria used by the algorithm. This work has been done in collaboration with Ann Mathew.

Ananta C. Pradhan

Ultraviolet Imaging Telescope (UVIT) observation of the galactic globular cluster NGC 7492

We present detailed photometric observations of the galactic globular cluster NGC 7492 using the data obtained with two far-ultraviolet (FUV: 1300 - 1800 Å), and three near-ultraviolet (NUV: 2000 - 3000 Å) filters of Ultraviolet Imaging Telescope (UVIT) on-board the *AstroSat* satellite. We confirmed the cluster membership of the extracted sources using GAIA data release 2 (Gaia DR2) proper motion data. We have used colour-magnitude diagrams (CMDs) using



UVIT and GAIA filters to separate out different evolutionary stages of the stars present in the cluster. We have identified a new extreme horizontal branch (EHB) star at the core of the cluster using UV and UV-optical CMDs. The estimated distance-modulus of the cluster is 16.95 ± 0.05 obtained by fitting BaSTI isochrones with cluster parameters, $[Fe/H] = -1.8$ dex and age = 12.0 Gyr on the $V - I$ vs V CMD. Interestingly, only the EHB star and blue horizontal branch stars (BHBs) among the UV-bright hot sources are detected in FUV filters of UVIT. We have derived the effective temperature of BHBs using colour-temperature relation and spectral energy distributions (SEDs) of multi-band filters, which are in the range from 8,000 K to 10,500 K. We find a variation of He abundance of BHBs by fitting the BaSTI ZAHB. The range in the He abundance of the BHBs corresponding to the best fit isochrones is 0.247 to 0.350. We have studied the radial distribution of all the sources of the cluster detected in UVIT. The sources detected in FUV filters extend beyond the half light radius ($1.15'$) of the cluster, whereas the sources detected in NUV filters extend beyond the tidal radius ($9.2'$) of the cluster. This work has been carried out in collaboration with Ranjan Kumar, Abhisek Mohapatra, Ayush Maharana, Devendra K. Ojha, et al.

Study of galactic structure using UVIT/AstroSat star counts

The structure of our Galaxy has been studied from ultraviolet (UV) star counts obtained with the Ultra-Violet Imaging Telescope (UVIT) on board the *AstroSat* satellite, in Far-UV (FUV) and Near-UV (NUV) bands. The F154W (BaF2) and N263M (NUVB4) filters were used in the FUV and NUV bands, respectively. The point sources are separated from the extra-galactic sources of UVIT observations using infrared (IR) colour cut method. The observed UVIT star counts match well with the simulations obtained from the Besançon model of stellar population synthesis towards several galactic directions. We also estimated the scale length and scale height of the thick disc and the scale height of the thin disc using the space density function and the exponential density law for the stars of intermediate galactic latitudes. The scale length of the thick disc ranges from 3.11 to 5.40 kpc, whereas the scale height ranges from 530 ± 32 pc to 630 ± 29 pc. The scale height of the thin disc

comes out to be in the range of 230 ± 20 pc to 330 ± 11 pc. This work is done in collaboration with Ranjan Kumar, Devendra K. Ojha, Sonika piridi, Tapas Baug, et al.

Anirudh Pradhan

Friedmann-Robertson-Walker accelerating Universe with interactive dark energy

We have presented an FLRW universe containing two-fluids (baryonic and dark energy), by assuming the deceleration parameter as a linear function of the Hubble function. This results in a time-dependent deceleration parameter (DP) having a transition from past decelerating to the present accelerating universe. In this model, dark energy (DE) interacts with dust to produce a new law for the density. As per our model, our universe is at present in a phantom phase after passing through a quintessence phase in the past. The physical importance of the two-fluid scenario is described in various aspects. The model is shown to satisfy current observational constraints such as recent Planck results. Various cosmological parameters relating to the history of the universe have been investigated. This work has been done in collaboration with Gopi K. Goswami, Aroonkumar Beesham, and Archana Dixit.

Barrow HDE model for Statefinder diagnostic in FLRW universe

We have analyzed the Barrow holographic dark energy (BHDE) in the framework of the flat FLRW universe by considering the various estimations of Barrow exponent Δ . Here, we define BHDE, by applying the usual holographic principle at a cosmological system, for utilizing the Barrow entropy rather than the standard Bekenstein-Hawking. To understand the recent accelerated expansion of the universe, we have considered the Hubble horizon as the IR cut-off. The cosmological parameters, especially the density parameter (Ω_D), the equation of the state parameter (ω_D), energy density (ρ_D), and the deceleration parameter (q) are studied, and found the satisfactory behaviours. Moreover, we additionally focus on the two geometric diagnostics, the Statefinder (r, s) and $O_m(z)$ to discriminant BHDE model from the Λ CDM model. We have determined and plotted the trajectories of evolution for Statefinder (r, s), (r, q) and $O_m(z)$



diagnostic plane to understand the geometrical behaviour by utilizing Planck 2018 observational information. Finally, we have explored the new Barrow exponent Δ , which strongly affect the dark energy equation of state that can lead it to lie in the quintessence regime, phantom regime, and exhibits the phantom-divide line during the cosmological evolution. This work has been done in collaboration with Archana Dixit, and Vinod K. Bhardwaj.

Ramprasad Prajapati

Gravitational instability with dust charge gradient and ion drag forces in unmagnetized dusty plasma

The influence of dust charge gradient force and ion drag force on the fragmentation of unmagnetized, self-gravitating dust cloud has been studied. The thermal electrons satisfy the Boltzmann relation, while inertialess ions are affected by the ion-neutral collisions. The dynamics of dusty fluid are modified by ion drag, charge gradient, and gravitational forces. The onset criterion of pinching instability and gravitational instability is derived. The pinching instability depends upon the critical ion drag coefficient and dust charge variation parameter. In the laboratory, complex plasma, with finite dust charge variations, the ion drag coefficient larger than the critical value causes pinching instability. This results in the fragmentation of the dusty cloud, which is affected due to the dust charge variations. The ion drag coefficient has destabilizing, while the dust charge variation parameter has stabilizing influence on the growth rate of the linear gravitational instability. The results have been discussed to understand the dust cloud collapse in the astrophysical system. This work has been done in collaboration with Bivash Dolai.

Effects of dust-charge gradient and polarization forces on the waves and Jeans instability in strongly coupled dusty plasma

The effects of dust charge gradient (DCG) force and polarization force have been investigated on the properties of dust acoustic wave (DAW) and linear Jeans instability in strongly coupled dusty plasma. In the kinetic regime, DCG and polarization forces modify the DAW mode and couple with compressional viscoelastic wave mode. The Jeans instability criterion and critical wave

number have been modified due to DCG force, polarization force, and strong coupling effects. The results have been discussed in the warm photo-disassociation region and in the laboratory complex plasmas. The strong correlation effect and the charge variation parameter stabilize the growth rate of Jeans instability. But, the polarization parameter stabilize the growth rate for positively charged dust grains and destabilize for negatively charged dust grains. The implications of charge gradient and polarization parameters are discussed for lower and higher charges in the laboratory complex plasma, which decreases the growth of the propagating DAW. This work has been done in collaboration with Bivash Dolai .

Farook Rahaman

Colour-flavour locked quark stars in energy-momentum squared gravity

Several attempts have been made in the past decades to search for the true ground state of the dense matter at sufficiently large densities and low temperatures via compact astrophysical objects. Focusing on strange stars, we derive the hydrostatic equilibrium assuming a maximally symmetric phase of homogeneous super-conducting quark matter called the *colour-flavour-locked* (CFL) phase in the background of energy-momentum squared gravity (EMSG). Theoretical and experimental investigations show that strange quark matter (SQM) in a CFL state can be the true ground state of hadronic matter at least for asymptotic densities, and even if the unequal quark masses. Motivated by these theoretical models, we explore the structure of stellar objects in recently proposed EMSG, which allows a correction term $T_{\mu\nu}T_{\mu\nu}$ in the action functional of the theory. Interestingly, EMSG may be effective to resolve the problems at high energy densities, e.g., relevant to the early universe and dense compact astrophysical objects without invoking some new forms of fluid stress, such as bulk viscosity or scalar fields. Finally, we solve the complicated field equations numerically to obtain the mass-radius relations for strange stars in CFL equation of state. This work has been done in collaboration with Ksh. Newton Singh, Ayan Banerje, and Sunil K. Maurya.



Conformally symmetric traversable wormholes in modified teleparallel gravity

We consider wormhole geometries in the context of teleparallel equivalent of general relativity (TEGR) as well as $f(T)$ gravity. The TEGR is an alternative geometrical formulation of Einstein's general relativity, where modified teleparallel gravity or $f(T)$ gravity has been invoked as an alternative approach for explaining an accelerated expansion of the universe. We present the analytical solutions under the assumption of spherical symmetry, and the existence of a conformal Killing vectors to proceed a more systematic approach in searching for exact wormhole solutions. More precisely, the existence of a conformal symmetry places restrictions on the model. Considering the field equations with a diagonal tetrad and anisotropic distribution of the fluid, we study the properties of traversable wormholes in TEGR that violates the weak and the null energy conditions at the throat and its vicinity. In the second part, wormhole solutions are constructed in the framework of $f(T)$ gravity, where T represents torsion scalar. As a consistency check, we also discuss the behaviour of energy conditions with a viable power-law $f(T)$ model and the corresponding shape functions. In addition, a wide variety of solutions are deduced by considering a linear equation of state relating the density and pressure, for the isotropic and anisotropic pressure, independently of the shape functions, and various phantom wormhole geometries are explored. This work has been done in collaboration with Ksh. Newton Singh, Ayan Banerjee, and Mahmood K. Jasim.

Chayan Ranjit

Constraints on energy momentum squared gravity from cosmic chronometers and supernovae Type Ia data

We perform an observational data analysis on the energy momentum squared gravity model. Possible solutions for matter density are obtained from the model and their cosmological implications are studied. Some recent observational data is used to constrain model parameters using statistical techniques. We have used the cosmic chronometer and SNe Type-Ia Riess (292) $H(z)-z$ data-sets, We have also used baryon acoustic oscillation (BAO) peak parameter and cosmic microwave background (CMB) peak parameter to obtain bounds on the

model parameters. For the statistical analysis, we have used the minimization technique of the χ^2 statistic. Confidence contours have been generated for the predicted values of the free parameters at the 66%, 90% and 99% confidence levels. Finally, we have compared our analysis with the union2 data sample presented by Amanullah, et al. 2010, and the recently published Pantheon data sample. A multi-component model is investigated by adding dust to a general cosmological fluid with equation of state $w = -1/3$. The density parameters were studied and their values were found to comply with the observational results. This work has been done in collaboration with Prabir Rudra, and Sujata Kundu.

Compact stellar models in modified gravity

We have considered that the compact objects are following a spherically symmetric static metric and obtained the Einstein field equations in the spacetime of $f(T, \mathcal{T})$. To make the Einstein equations solvable, we employ the methodology of conformal Killing vectors. Thereafter, by using the MIT Bag equation of state to the compact stars, considering that the stars are formed by strange quark, we find the solutions set. The solutions are examined via several physical testings which exhibit viability of the model. This work has been done in collaboration with Ines G. Salako, Maxim Khlopov, Saibal Ray, and Utpal Mukhopadhyay.

Shantanu Rastogi

Detection of PAH and nbL features in planetary nebulae NGC 7027 and BD +30° 3639 with TIRCAM2 instrument on 3.6 m DOT

High resolution infrared imaging observations of the young Planetary Nebulae NGC 7027 and BD +30° 3639, taken with the newly installed TIFR Infrared Camera-II (TIRCAM2) on 3.6m Devasthal Optical Telescope (DOT), ARIES, Nainital, are being reported. The images are acquired in J, H, K, polycyclic aromatic hydrocarbon (PAH) and narrow-band L (nbL) filters. The observations show emission from warm dust and PAHs in the circumstellar shells. The imaging of the two objects are among the first observations in PAH and nbL bands using TIRCAM2 on DOT. The NGC 7027 images in all bands show similar elliptical morphology with $\sim 6''.7$ and $\sim 4''.5$ semi-major and semi-minor axes. Considering size up to



10% of peak value, the nebula extends upto 8 " from the central star revealing a multi-polar evolution. The relatively cooler BD +30° 3639 shows a rectangular-ring shaped nebula. In J and H bands, it shows an angular diameter of ~ 8 ", while a smaller ~ 6 " size is observed in K, PAH and nBL bands. The $3.28 \mu\text{m}$ emission indicates presence of PAHs at about 6,000 and 5,000 AU from the central stars in NGC 7027, and BD +30° 3639 respectively. Analysis suggests domination of neutral PAHs in BD +30° 3639, while in NGC 7027 there is higher ionization and more processed PAH population. This work has been done in collaboration with Rahul K. Anand, Brijesh Kumar, Arpan Ghosh, Saurabh Sharma, et al.

Response of ambient BC concentration across the Indian region to the nation-wide lockdown: Results from the ARFINET measurements of ISRO-GBP

We assess the response of ambient aerosol black carbon (BC) mass concentrations and spectral absorption properties across Indian mainland during the nation-wide lockdown (LD) in connection with the Corona virus Disease 19 (COVID-19) pandemic. The LD had brought near to total cut-off of emissions from industrial, traffic (road, railways, marine, and air) and energy sectors, though the domestic emissions remained fairly unaltered. This provided a unique opportunity to delineate the impact of fossil fuel combustion sources on atmospheric BC characteristics. In this context, the primary data of BC measured at the national network of aerosol observatories (ARFINET) under ISRO-GBP are examined to assess the response to the seizure of emissions over distinct geographic parts of the country. Results indicate that average BC concentrations over the Indian mainland are curbed down significantly (10-40%) from prelockdown observations during the first and most intense phase of lockdown. This decline is significant with respect to the long-term (2015-2019) averaged (climatological mean) values. The drop in BC is most pronounced over the Indo-Gangetic Plain ($> 60\%$) and north-eastern India ($> 30\%$) during the second phase of lockdown, while significant reduction is seen during LD1 (16-60%) over central and peninsular Indian as well as Himalayan and sub-Himalayan regions. Despite such a large reduction, the absolute magnitude of BC remained higher over the IGP and north-eastern sites

compared to other parts of India. Notably, the spectral absorption index of aerosols changed very little over most of the locations, indicating the still persisting contribution of fossil-fuel emissions over most of the locations. This work has been done in collaboration with Mukunda M. Gogoi, S.Suresh Babu, B. S. Arun, K. Krishna Moorthy, et al.

C. D. Ravikumar

Central intensity ratio of early-type galaxies in low-density environment

We have extended the study of Central Intensity Ratio (CIR) by selecting a sample of 52 early-type galaxies from low density environment to be negatively observed with high resolution optical observation from Hubble Space Telescope, and reported significant correlations with the mass of the central super-massive black hole, central velocity dispersion, absolute B-band magnitude, stellar bulge mass, and central Mg 2 index of the host galaxy. The study proposes the use of CIR as a simple, fast, and efficient photometric tool for exploring the co-evolution scenario existing in galaxies, and has been done in collaboration with K. Sruthi

Heavy quarkonium properties at finite temperature in strongly coupled quark gluon plasma

We have tried to understand the heavy quarkonium properties at finite temperature by solving the N-dimensional radial Schrödinger equation using the Analytical Exact Iteration method. The two body potential in strongly coupled quark gluon plasma was used. The energy eigen values were estimated in the N-dimensional space for any state (n, l). The variations of binding energy and mass spectra with temperature were explored in the N-dimensional space, and estimations for dissociation temperatures for different states of quarkonia were calculated. This work has been done in collaboration with K. T. Rethika, and V. M. Bannur.

Saibal Ray

Decoupling gravitational sources in $f(R, T)$ gravity under class I spacetime

We have presented a simple and effective new methodology to build up self-gravitating structures



driven by an imperfect fluid distributions. This approach is developed within the framework of $f(R, T)$ gravity theory by combining two geometrical schemes, the gravitational decoupling by means of minimal geometric deformation and the embedding technique, specifically the class I grasp. The former, allows to introduce extra matter fields into the system, modifying the energy momentum tensor, as well as new degrees of freedom altering the mass function and its associated metric potential, i.e., the g_{rr} component. On the other hand the class I focusing, provides precious and useful mathematical information to determine the full geometrical description of the internal spacetime. Furthermore, to obtain the final form of the modified material content, the so-called mimic constraint procedure is employed. To check the mathematical, physical and astrophysical viability of the present proposal, the authors have framed a detailed discussion on the matching condition process and studied the effects introduced by the mimic constraint approach on the mass function. Finally, to support the feasibility of the results a thorough graphical analysis is performed. This has been studied in collaboration with Sunil K. Maurya, and Francisco Tello-Ortiz.

N. R. Sen : Father of Indian applied mathematics

Nikhil Ranjan Sen (1894 - 1963), popularly known as N.R. Sen, is known as the Father of Applied Mathematics, and founder of the Calcutta School of Relativity Theory. He did Ph.D. in Berlin under the Nobel Laureate Max von Laue. In Berlin, he came in contact with renowned physicists like Max Planck, Albert Einstein and their contemporaries. This article is based on the primary sources, discusses the lesser known facts of his life, like the beginning of scientific career, background of his D.Sc. as well as Ph.D. theses, and detailed summary of his scientific works. This article is written collaboration with Utpal Mukhopadhyay, and Ranjinder Singh.

Prabir Rudra

Thermodynamics in $f(R, \mathcal{L})$ theories: Apparent horizon in the FLRW spacetime

The uniqueness of these theories lies in the fact that the spacetime curvature is coupled to the baryonic matter instead of exotic matter (in

the form of scalar field). We investigate the viability of these theories from the point of view of the thermodynamic stability of the models. To be more precise here, we are concerned with the thermodynamics of the apparent horizon of Friedmann-Lemaitre-Robertson-Walker (FLRW) spacetime in the background of the $f(R, \mathcal{L})$ theory. We consider several models of $f(R, \mathcal{L})$ theories, where both minimal and non-minimal coupling has been considered. Various thermodynamic quantities like entropy, enthalpy, internal energy, Gibbs free energy, etc. are computed, and using their allowed ranges, various model parameters are constrained. This work has been done in collaboration with Behnam Pourhassan.

Note on the thermodynamic stability of a black ring at quantum scales

The thermodynamic properties of a thin black ring in AdS spacetime is explored when the size of the ring is comparable to quantum scales. The angular momentum to mass ratio of this system has an upper limit, which is the cosmological radius of the black ring. It is found that the small black ring will be thermodynamically stable due to the effects introduced by thermal fluctuations. However, we find that the black ring is less stable than thermal AdS. Thermodynamic analysis indicates that there is no critical point, but there is Hawking-Page transition to radiation, which is confirmed by the Gibbs free energy analysis. This work has been done in collaboration with Robert B. Mann, and Behnam Pourhassan.

Sanjay K. Sahay

DRLDO: A novel DRL based de-obfuscation system for defense against Metamorphic malware

We propose a novel mechanism to normalize metamorphic and obfuscated malware down at the opcode level and hence create an advanced metamorphic malware de-obfuscation and defense system. With the inclusion of the DRLDO as a sub-component, an existing intrusion detection system could be augmented with defensive capabilities against 'zero-day' attacks from obfuscated and metamorphic variants of existing malware. This gains importance, not only because there exists no system to date that uses advanced DRL to intelligently and automatically normalize obfuscation down even to



the opcode level, but also because the DRLDO system does not mandate any changes to the existing IDS. The DRLDO system does not even mandate the IDS' classifier to be retrained with any new dataset containing obfuscated samples. Hence, DRLDO could be easily retrofitted into any existing IDS deployment. Experimental results prove that DRLDO was able to successfully make the otherwise un-detectable obfuscated variants of the malware detectable by an existing pre-trained malware classifier. Further, the de-obfuscated variants generated by DRLDO achieved a very high correlation (of 0.99) with the base malware. This observation validates that the DRLDO system is actually learning to de-obfuscate and not exploiting a trivial trick. This work has been done in collaboration with Mohit Sewak, and Hemant Rathore

Privacy-preserving mutual authentication and key agreement scheme for multi-server healthcare system

The usage of different technologies and smart devices help to get medical services remotely for multiple benefits. Thus, critical and sensitive data is exchanged between a user and a doctor. When health data is transmitted over a common channel, it becomes essential to preserve various privacy and security properties in the system. Further, the number of users for remote services is increasing day-by-day exponentially, and thus, it is not adequate to deal with all users using the one server due to the verification overhead, server failure, and scalability issues. Thus, researchers proposed various authentication protocols for multi-server architecture, but most of them are vulnerable to different security attacks and require high computational resources during the implementation. To tackle privacy and security issues using less computational resources, we propose a privacy-preserving mutual authentication and key agreement protocol for a multi-server healthcare system. We discuss the proposed schemes security analysis and performance results to understand its security strengths and the computational resource requirement. Further, we do the comparison of security and performance results with recent relevant authentication protocols. This work has been done in collaboration with Trupil Limbasiya, and Bharath Sridharan.

Sandeep Sahijpal

Thermodynamics of dust condensation around the dimming Betelgeuse

Betelgeuse is one of the brightest red super-giant (RSG) stars, because of its proximity to the solar system. This makes it important when deducing the features and evolutionary phases of RSG stars. Betelgeuse has always been a well-observed target, especially during the past year, because of the reduction in its brightness. It has been speculated that the star is in its last evolutionary stage(s), and that, it is soon going to explode. However, in recent work, it has been proposed that the episodic mass loss and dust condensation around the star are major reasons for the reduction in its brightness. We have performed detailed thermodynamical equilibrium and non-equilibrium calculations of the condensation of dust grains around the cooling envelope of Betelgeuse. Based on the deduced chemical composition, we have ventured to determine the nature of dust that could condense in the stellar winds. The dust grains are essentially found to be oxides of Al, Ca and Ti, and silicates of Al, Ca, Mg and Fe-metal. Further, we have determined the normalized masses of the dust grains of various compositions that could be present around the star and could be causing the reduction in its brightness. This work has been done in collaboration with Anuj Gupta.

Gauranga C. Samanta

Gravitational lensing effect in traversable wormholes

We study the effect of strong gravitational lensing in the context of charged wormhole. The conditions determining the existence of photon spheres at and outside the throat are obtained. The necessary and sufficient conditions for the existence of photon spheres at or outside the throat of the charged wormhole are derived. Furthermore, photon spheres are investigated in three cases for three different forms of redshift function. These three cases include the existence of effective photon spheres (i) at the throat, (ii) outside the throat and (iii) both at and outside the throat. Consequently, these provide the information about the formation of infinite number of concentric rings and may lead to the detection of wormhole geometries. This work has been done in collaboration with Nisha Godani.



Cosmological dynamics in R^2 gravity with logarithmic trace term

A novel function for modified gravity is proposed, $f(R, T) = R + \lambda R^2 + 2\beta \ln(T)$, with constants λ and β , scalar curvature R , and the trace of stress energy tensor T , satisfying $T = \rho - 3p > 0$. Subsequently, two equations of state (EoS) parameters, namely ω and a parametric form of the Hubble parameter H , are employed in order to study the accelerated expansion and initial cosmological bounce of the corresponding universe. Hubble telescope experimental data for redshift z within the range $0.07 \leq z \leq 2.34$ are used to compare the theoretical and observational values of the Hubble parameter. Moreover, it is observed that all the energy conditions are fulfilled within a neighbourhood of the bouncing point $t = 0$, which shows that the necessary condition for violation of the null energy condition, within a neighbourhood of the bouncing point in general relativity, could be avoided by modifying the theory in a reasonable way. Furthermore, a large amount of negative pressure is found, which helps to understand the late time accelerated expansion phase of the universe. This work has been done in collaboration with Emilio Elizaldo, and Nisha Godani.

Rathin Sarma and Amit Pathak

NuSTAR observation of Ark 564 reveals the variation of coronal temperature with flux

Earlier we studied spectral variability of X-ray bright AGN Ark 564 using NuSTAR observation. We performed flux-resolved spectroscopy for NuSTAR data of Ark 564 and found an evidence of Compton up-scattering process occurs in the corona. We extended similar works to another AGN ES0103-035 since using NUSTAR data. Buisson, et al. found a low temperature corona in the source. Interestingly ES0103-035 exhibits completely opposite behaviour in comparison to Ark 564. The coronal temperature is found to increase with flux. The results may be understood in a framework where AGN variability is either dominated by coronal heating variation leading to correlated increase of temperature with flux, and the opposite effect being seen when the variability is dominated by changes in the seed photon flux. In order to study the variability of a source in different energy ranges, the fractional variability is a very useful tool. We have tried to develop a simple

method that can predict the fractional variability for highly variable NLS1 galaxy. Initially we have checked our result for different observations of MRK335 and found satisfactory result. This work has been done in collaboration with Samuzal Barua, Ranjeev Misra, and Biman J. Medhi.

Anjan A. Sen

Is there an early Universe solution to Hubble tension?

We consider a low redshift ($z < 0.7$) cosmological data set comprising megamasers, cosmic chronometers, type Ia SNe and BAO, which we bin according to their redshift. For each bin, we read the value of H_0 by fitting directly to the flat Λ CDM model. Doing so, we find that H_0 descends with redshift, allowing one to fit a line with a non-zero slope of statistical significance 2.1σ . Our analysis rests on the use of cosmic chronometers to break a degeneracy in BAO data, and it will be imperative to revisit this feature as data improves. Nevertheless, our results provide the first independent indication of the descending trend reported by the H0LiCOW collaboration. If substantiated going forward, early Universe solutions to the Hubble tension will struggle explaining this trend. This work is done in collaboration with Chethan Krishnan, Eoin O. Colgain, Ruchika Koushik, M.M. Sheikh-Jabbari, et al.

A study on cubic Galileon gravity using N-body simulations

We use N-body simulation to study the structure formation in the cubic Galileon gravity model, where along with the usual kinetic and potential term, we also have a higher derivative self-interaction term. We find that the large scale structure provides a unique constraining power for this model. The matter power spectrum, halo mass function, galaxy-galaxy weak lensing signal, marked density power spectrum as well as count in cell are measured. The simulations show that there are less massive halos in the cubic Galileon gravity model than corresponding Λ CDM model, and the marked density power spectrum in these two models are different by more than 10%. Furthermore, this model shows significant differences in voids compared to Λ CDM. The number of low density cells is far higher than



that in the Λ CDM model. Therefore, it would be interesting to put constraints on this model using future large scale structure observations, especially in void regions. This work is done in collaboration with Jiajun Zhang, Bikash R. Dinda, Md. Wali Hossain, and Wentao Luo.

Asoke K. Sen

Change in the direction of polarization vector and redshift of an incoming light ray as observed from a rotating frame

The change in the direction of the polarization vector calculated here is only due to the effect of the non-inertial rotating frame, considering that the light source is at a distance, and it is emitting plane-polarized light. The metric tensors for a rotating observer have been collected from existing literature. Accordingly, the electric displacement and magnetic induction values as applicable for a rotating observer have been calculated. These values are used to calculate the change in the orientation of the electric vector of an incoming plane-polarized light ray. Earth has been taken as an example of a rotating frame and the calculated amount of change in the direction of the polarization vector has been found to be dependent on the azimuthal and polar coordinates of the rotating frame. We also discuss the redshift as observed by a rotating observer, and the value of the redshift has been calculated for an observer sitting on a rotating earth. This work has been done in collaboration with Tanay Ghosh.

Comparison of light scattering properties of porous dust particle with connected or unconnected dipoles

We propose a comparative study of optical properties in the visual spectral regime of porous dust particles having porosities ranging from 0% (compact particle) to 50% (as much matter as void in a same particle), generated using two different models considering particle as an ensemble of dipoles much smaller than wavelength. One of the models (the touching-dipoles model, named: TD model) considers a homogeneous structure made up of touching dipoles (that is neighbouring); the dipoles are removed randomly one by one from a compact structure in such a way that the remaining structure is left connected. The other model (the non-touching-dipoles model, named: non-TD model) generates porous particles by

randomly removing dipoles without constraining the ensemble of dipoles to remain connected. The computations of the optical properties of these disordered particles are performed using Discrete Dipole Approximation (DDA) code. Linear polarization profiles and colour (i.e., the ratio between the intensities of the light scattered by particles in the comet at 0.485 m and 0.684 μm wavelengths expressed in log scale) curves are shown vs. the scattering angle, and compared for the two models at different porosities. The variation of scattering efficiency factor as a function of the size parameter (X) is also studied to point out sensitivity of light scattering to different pore structures (shape and size), comparing data from particles of same porosity but generated through different processes. The results are compared with Mie results where the effective refractive index for each porosity is calculated using Bruggemann mixing rule. It is observed that light scattering properties of the TD model is not much different from the EMT-Mie model, but the non-TD model differs significantly. These difference could be due to the fact that non-TD model contains a higher number of non-Rayleigh inclusions, as compared to the TD model. This work has been done in collaboration with Naznin R. Choudhury, Rosario Vilaplana, and Robert Botet.

Somasri Sen

Identifying the radiative components responsible for quasi-periodic oscillations of black hole systems

While the dynamical origin of the variability observed in galactic black hole systems, such as quasi-periodic oscillations (QPOs), it is still a matter of debate, and insight into the radiative components responsible for such behaviour can be obtained by studying their energy-dependent temporal behaviour. In particular, one needs to ascertain which variations of the parameters of the best-fitting time-averaged spectral components reproduce the observed energy-dependent fractional rms and time-lags. However, to obtain meaningful interpretation, the standard spectral component parameters have to be recast to physically relevant ones. Then, the energy-dependent temporal variations that their fluctuations will cause, needs to be predicted and compared with observations. We describe a generic method to do this and apply the technique to the



~ 3 -4 Hz QPOs observed in the black hole system GRS 1915+105 as observed by AstroSat, where the time-averaged spectra can be represented by emission from a truncated disc and hot thermal Comptonizing coronae in the inner regions. We find that the QPOs and their harmonic can be explained in terms of correlated local accretion rate variations in the disc, the truncated disc radius, the optical depth and the heating rate of the coronae with time-delays between them. We highlight the potential of such techniques to unravel the radiative process responsible for variability using high-quality spectral and temporal data from AstroSat and NICER. This work has been done in collaboration with Akash Garg, and Ranjeev Misra.

Ranjan Sharma

An electromagnetic extension of the Schwarzschild interior solution and the corresponding Buchdahl limit

We construct a model for charged star as a generalization of the uniform density Schwarzschild interior solution. We employ the Vaidya and Tikekar ansatz for one of the metric potentials and electric field is chosen in such a way that when it is switched off the metric reduces to the Schwarzschild. This relates charge distribution to the Vaidya-Tikekar parameter, k , indicating deviation from sphericity of three dimensional space when embedded into four dimensional Euclidean space. The model is examined against all the physical conditions required for a relativistic charged fluid sphere as an interior to a charged star. We also obtain and discuss charged analogue of the Buchdahl compactness bound. This work is done in collaboration with Naresh Dadhich, Shyam Das, and Sunil D. Maharaj

Electromagnetic and anisotropic generalization of a plethora of well-known solutions describing relativistic compact objects

We demonstrate a technique to generate new class of exact solutions to the Einstein-Maxwell system describing a static spherically symmetric relativistic star with anisotropic matter distribution. An interesting feature of the new class of solutions is that one can easily switch off the electric and/or anisotropic effects in this formulation. Consequently, we show that

a plethora of well known stellar solutions can be identified as sub-class of our class of solutions. We demonstrate that it is possible to express our class of solutions in a simple closed form so as to examine its physical viability for the studies of relativistic compact stars. This work is done in collaboration with Kalikkudy Komathiraj.

Umesh K. Sharma

Barrow agegraphic dark energy

We propose a new dark energy model by applying the Barrow entropy and the holographic principle, with a time scale as IR cut off. Analysing the conformal time as well as universe's age as infrared cut-offs, we explore the cosmological importance of the suggested dark energy models and examine the universe evolution filled with the proposed DE applicants and a pressure-less matter. We observe that the equation of state, deceleration, the density parameters can present adequate nature, and these models may also explain the late-time acceleration though, the proposed models are unstable except some values of Barrow exponent Δ . Furthermore, we mention the consequences of the presence of interaction among the universe sectors. This work is done in collaboration with Gunjan Varshney, and Vipin C. Dubey.

Reconstruction of quintessence field for the THDE with swampland correspondence in $f(R,T)$ gravity

We construct the Tsallis holographic quintessence model of dark energy in $f(R,T)$ gravity with Hubble horizon as infrared (IR) cutoff. In a flat Friedmann-Robertson-Walker (FRW) background, the correspondence among the energy density of the quintessence model with the Tsallis holographic density permits the reconstruction of the dynamics and the potentials for the quintessence field. The suggested Hubble horizon IR cut-off for the Tsallis holographic dark energy (THDE) density acts for two specific cases: (i) THDE 1, and (ii) THDE 2. We have reconstructed the Tsallis holographic quintessence model in the region $\omega_\Lambda > -1$ for the EoS parameter for both the cases. We investigate the behaviour of several well-known Statefinder quantities, like the deceleration parameter, the jerk, and the parameter s . In addition, the quintessence phase of the THDE models is analyzed with swampland conjecture to describe the accelerated expansion of the universe.



Gyan P. Singh

Study of particle creation with quadratic equation of state in higher derivative theory

We investigate the effect of particle creation in flat Friedmann-Lemaître-Robertson-Walker (FLRW) spacetime under the higher derivative theory composition. The exact solution of the field equation in higher derivative theory obtained by considering the quadratic equation of state, $p = \omega\rho^2 - \rho$, and different forms of deceleration parameter. The physical acceptance and stability of the models are explored by discussing energy conditions and squared sound speed. In addition to that, the statefinder diagnostic pair $\{r, s\}$ also scrutinized to measure the deviation of considered models from Λ cold dark matter (Λ CDM) model. This work has been done in collaboration with Ashwini R. Lalke, and Nikhil Hulke.

Some Bianchi I dark energy models in Brans-Dicke theory

This work deals with the study of interacting and non-interacting dark energy and dark matter in the spatially homogeneous and anisotropic Bianchi I spacetime within the framework of Brans-Dicke scalar-tensor theory of gravitation. As the set of field equations is not closed, exact solutions are obtained using power-law relation and assuming a linearly varying deceleration parameter. The physical acceptability and stability of the obtained model are scrutinized using energy conditions and square sound speed. The statefinder diagnostic method is adopted to discuss and measure the deviation of the considered model from the Λ cold dark matter (Λ CDM) model. This work has been done in collaboration with Ashwini R. Lalke, and Nikhil Hulke.

Harinder P. Singh

APOGEE discovery of a chemically atypical star disrupted from NGC 6723 and captured by the Milky Way bulge

The central ('bulge') region of the Milky Way is teeming with a significant fraction of mildly metal-deficient stars with atmospheres that are strongly enriched in cyanogen ($^{12}\text{C}^{14}\text{N}$). Some of these objects, which are also known as nitrogen-enhanced stars, are hypothesised to be relics of the ancient assembly history

of the Milky Way. Although the chemical similarity of nitrogen-enhanced stars to the unique chemical patterns observed in globular clusters has been observed, a direct connection between field stars and globular clusters has not yet been proven. In this work, we report on high-resolution, near-infrared spectroscopic observations of the bulge globular cluster NGC 6723, and the serendipitous discovery of a star, 2M18594405-3651518, located outside the cluster (near the tidal radius) but moving on a similar orbit, providing the first clear piece of evidence of a star that was very likely once a cluster member and has recently been ejected. Its nitrogen abundance ratio ($[\text{N}/\text{Fe}] \gtrsim +0.94$) is well above the typical Galactic field-star levels, and it exhibits noticeable enrichment in the heavy s-process elements (Ce, Nd, and Yb), along with moderate carbon enrichment; all characteristics are known examples in globular clusters. This result suggests that some of the nitrogen-enhanced stars in the bulge likely originated from the tidal disruption of globular clusters. This work has been done in collaboration with Jose G. Fernandez-Trincado, Timothy C. Beers, Dante Minniti, and Leticia Carigi, et al.

RR Lyrae variables in Messier 53: Near-infrared period-luminosity relations and the calibration using Gaia early data release 3

We present new near-infrared, JHK_s , period-luminosity relations (PLRs) for RR Lyrae variables in the Messier 53 (M53 or NGC 5024) globular cluster. Multi-epoch JHK_s observations, obtained with the WIRCam instrument on the 3.6-m Canada-France Hawaii Telescope, are used for the first time to estimate precise mean-magnitudes for 63 RR Lyrae stars in M53 including 29 fundamental-mode (RRab) and 34 first-overtone mode (RRc) variables. The JHK_s -band PLRs for RR Lyrae stars are best constrained for RRab types with a minimal scatter of 22, 23, and 19 mmag, respectively. The combined sample of RR Lyrae is used to derive the K_s -band PLR, $K_s = -2.303(0.063) \log P + 15.212(0.016)$ exhibiting a 1σ dispersion of only 0.027 mag. Theoretical period-luminosity-metallicity (PLZ) relations are used to predict parallaxes for 400 Galactic RR Lyrae resulting in a median parallax zero-point offset of $-7 \pm 3 \mu\text{as}$ in *Gaia*



early data release 3 (EDR3), which increases to $22 \pm 2 \mu\text{as}$ if the parallax corrections are applied. We also estimate a robust distance modulus, $\mu_{\text{M53}} = 16.403 \pm 0.024$ (statistical) ± 0.033 (systematic) mag, to M53 based on theoretical calibrations. Homogeneous and precise mean-magnitudes for RR Lyrae in M53 together with similar literature data for M3, M4, M5 and ω Cen are used to empirically calibrate a new RR Lyrae PLZ $_{K_s}$ relation, $K_s = -0.848(0.007) - 2.320(0.006) \log P + 0.166(0.011)[\text{Fe}/\text{H}]$, anchored with *Gaia* EDR3 distances and theoretically predicted relations, and simultaneously estimate precise RR Lyrae based distances to these globular clusters. This work has been done in collaboration with Anupam Bhardwaj, Marina Rejkuba, Richard de Grijs, and Soung-Chul Yang, et al.

Monika Sinha

Dense matter equation of state of massive neutron star with antikaon condensation

Recent measurements of neutron star mass from several candidates (PSR J1614–2230, PSR J0348+0432, MSP J0740+6620) set the lower bound on the maximum possible mass for this class of compact objects $\sim 2 M_\odot$. Existence of stars with high mass brings the possibility of existence of exotic matter (hyperons, meson condensates) at the core region of the objects. We investigate the (anti)kaon (K^- , $\bar{K}^0$) condensation in β -equilibrated nuclear matter within the framework of covariant density functional theory. The functionals in the kaonic sector are constrained by the experimental studies on K^- atomic, kaon-nucleon scattering data fits. We find that the equation of state softens with the inclusion of (anti)kaon condensates, which lowers the maximum mass of neutron star. In one of the density-independent coupling cases, the K^- condensation is through a first-order phase transition type, which produces a $2 M_\odot$ neutron star. The first-order phase transition results in mixed phase region in the inner core of the stars. While $\bar{K}^0$ condensation appears via second-order phase transition for all the models we consider here. This work has been done in collaboration with Vivek B. Thapa.

Massive Δ -resonance admixed hypernuclear stars with antikaon condensations

We study the effect of (anti)kaon condensation on the properties of compact stars that develop hyper-nuclear cores with and without an admixture of Δ -resonances. We work within the covariant density functional theory with the parameters adjusted to K -atomic and kaon-nucleon scattering data in the kaonic sector. The density-dependent parameters in the hyperonic sector are adjusted to the data on Λ and Ξ^- hyper-nuclei data. The Δ -resonance couplings are tuned to the data obtained from their scattering off nuclei and heavy-ion collision experiments. We find that (anti)kaon condensate leads to a softening of the equation of state (EoS) and lower maximum masses of compact stars than in the absence of the condensate. Both the K^- and $\bar{K}^0$ -condensations occur through a second-order phase transition, which implies no mixed-phase formation. For large values of (anti)kaon and Δ -resonance potentials in symmetric nuclear matter, we observe that condensation leads to an extinction of $\Xi^{-,0}$ hyperons. We also investigate the influence of inclusion of additional hidden-strangeness σ^* meson in the functional, and find that it leads to a substantial softening of the equation of state and delay in the onset of (anti)kaons. This work has been done in collaboration with Vivek B. Thapa, Jia J. Li, and Armen Sedrakian.

L. Sriramkumar

Generating primordial features at large scales in two-field models of inflation:

We investigate the generation of features at large scales in the primordial power spectrum when inflation is driven by two scalar fields. In canonical single field models of inflation, these features are often generated due to deviations from the slow-roll regime. While deviations from slow-roll can be naturally achieved in two-field models due to a sharp turn in the trajectory in the field space, features at the largest scales of the types suggested by CMB temperature anisotropies are more difficult to achieve in models involving two canonical scalar fields due to the presence of isocurvature fluctuations. We show, instead, that a coupling between the kinetic terms of the scalar fields can easily produce such features. We discuss models whose theoretical predictions are



consistent with current observations and highlight the implications of our results. This work is done in collaboration with Matteo Braglia, Dhiraj K. Hazra, and Fabio Finelli,

Generating PBHs and small-scale GWs in two-field models of inflation

Primordial black holes (PBHs) generated by gravitational collapse of large primordial over densities can be a fraction of the observed dark matter. We introduce a mechanism to produce a large peak in the primordial power spectrum in two-field inflationary models characterized by two stages of inflation based on a large non-canonical kinetic coupling. This mechanism is generic to several two-field inflationary models, due to a temporary tachyonic instability of the isocurvature perturbations at the transition between the two stages of inflation. We numerically compute the primordial perturbations from largest scales to the small scales corresponding to that of PBHs using an extension of BINGO (BI-spectra and Non-Gaussianity Operator). Moreover We numerically compute the stochastic background of gravitational waves produced by second order scalar perturbations within frequencies ranging from nano-Hz to KHz that covers the observational scales corresponding to Pulsar Timing Arrays, Square Kilometer Array to that of Einstein telescope. We discuss the prospect of its detection by these proposed and upcoming gravitational waves experiments. This work is done in collaboration with Matteo Braglia, Dhiraj K. Hazra, Fabio Finelli, and George F. Smoot, et al.

Parijat Thakur

Probing transit timing variation and its possible origin with twelve new transits of TrES-3b

We have been working in the field of close-in transiting extra-solar planetary systems. We have observed total twelve transit observations of this system, which include six transits from the 2-m Himalayan Chandra Telescope (HCT), IAO, Hanle, five from the 1.3-m Devasthal telescope, ARIES, Nainital, and one transit from the 1.25-m AZT-11 telescope at the Crimean Astrophysical Observatory (CrAO), Crimea. In order to have the refine estimation of transit ephemeris and the precise TTV analysis, apart from our twelve new transit observations, seventy one more transit

data of this system were also considered from the literature. All these eighty three transit light curves were analyzed with uniform procedure through Transit Analysis package (TAP). By fitting a linear ephemeris model to mid-transit time data, we have derived a new linear ephemeris and obtained the timing residuals that suggests the possibility of TTV in the TrES-3 system. This analysis shows that the possible TTV is unlikely to be periodic, indicating the absence of an additional body in this system. It was theoretically predicted that the possible TTV may be due to the orbital decay and apsidal precession, induced by tidal interaction between the TrES-3b and its parent star. The orbital decay study shows decreasing period of TrES-3b with the decay rate equals to $-4.1 \pm 3.1 \text{ ms yr}^{-1}$. Corresponding to this decay rate, the estimated modified stellar tidal quality factor of $Q'_* \sim 1.11 \times 10^5$ is consistent with the theoretically predicted values for the stars hosting the hot-Jupiters. The shift in the transit arrival time of TrES-3b after 11 years is expected to be $T_{\text{shift}} \sim 69.55 \text{ s}$, which is consistent with the rms of the timing residuals. In addition to this, the estimated remaining lifetime of TrES-3b was found to be $\sim 24 \text{ Myr}$. From the apsidal precession study, the precession rate of the orbit of TrES-3 system was found to be $0.000472 \pm 0.000320 \text{ rad epoch}^{-1}$. Corresponding to this precession rate, the estimated planetary tidal Love number(k_p) of 1.15 ± 0.32 was found to be larger than that of Jupiter. This work has been done in collaboration with Vineet K. Mannaday, Img-Guey Jiang, Devendra K. Sahu, and Yogesh C. Joshi, et. al.

2016 Outburst of H 1743-322: XMM-Newton and NuSTAR View

We report the detection of a type C quasi-periodic oscillation (QPO) along with the upper harmonic in the commensurate ratio of 1:2 at the frequency of $\sim 1 \text{ Hz}$ and $\sim 2 \text{ Hz}$, respectively. We find a shift in the centroid frequency of the QPO and upper harmonic of the second observation with respect to the first one. The hardness intensity diagram implies that in contrast to the 2008 and 2014 failed outbursts, the 2016 outburst was a successful one. The shape of the power density spectra, the nature of the characteristic frequencies and the fractional rms amplitude of the timing features together imply that the source stayed in the low/hard



state during these observations. In addition, the photon index and the other spectral parameters also indicate the low/hard state behavior of the source. Apart from this, they also find hard time lags of 0.40 ± 0.15 s and 0.32 ± 0.07 s in the 0.07–0.4 Hz frequency range in the two observations during the 2016 outburst. The correlation between the photon index and the centroid frequency of the QPO implies the origin of the timing features from the coronal region. We find the energy spectrum to be dominated by a strong Comptonized fraction with a weak thermal component, which in turn also indicates that the QPO is being modulated by the Comptonization process. This work has been done in collaboration with Swadesh Chand, Vivek K. Agrawal, Gulab C. Dewangan, and Prakash Tripathi.

Sunil K. Tripathy

Gravastar in the framework of braneworld gravity

Gravastars have been considered as a serious alternative to black holes in the past couple of decades. Stable models of gravastar have been constructed in many of the alternate gravity models besides standard general relativity (GR). The Randall-Sundrum (RS) braneworld model has been a popular alternative to GR, especially in the cosmological and astrophysical context. Here, we consider a gravastar model in RS brane gravity. The mathematical solutions in different regions have been obtained with calculation of matching conditions. Various important physical parameters for the shell have been calculated and plotted to note their variation with radial distance. We also calculate and plot the surface redshift to provide a very cursory check on the stability of the gravastar within the purview of RS brane gravity. This work is done in collaboration with Rikpratik Sengupta, Shounak Ghosh, Saibal Ray, and Bivudutta Mishra.

Investigating the physical and geometrical parameters of the cosmological models with anisotropic background

We have investigated some accelerating cosmological models at the backdrop of an anisotropic metric in an extended gravity theory. Two viable cosmological models one with a little rip behaviour and the other with a hyperbolic form of Hubble parameter have been constructed.

The dynamical aspects of the models along with some physical and geometrical parameters are analysed. Both the models presented evolve in the phantom-like region and overlap with Λ CDM model at late times. We carried out a geometrical diagnosis of the model to show the viability of the models. This work is done in collaboration with Bivudutta Mishra

Vinutha Tummala

Dynamics of bianchi cosmological model in R^n gravity

The LRS Bianchi-I spatially homogeneous and anisotropic perfect fluid cosmological model is studied in $f(R, T)$ theory by specific choice of $f(R, T) = R + \alpha R^n + \lambda T$. To get the deceleration parameter as a function of time (t), the scale factor is considered as an increasing function of time. By using scale factor and the proportionality of shear scalar (σ) of the spacetime with expansion scalar (θ), the solution of the field equations is obtained, also to explain the accelerating expansion of the universe, the constant n plays a key role. It is observed that, for $n = 2, 2.5, 3, 3.5, 4$, the pressure and energy density are negative and positive respectively. For the remaining values of n , the pressure is positive, and the energy density is negative. Also, it is observed that, all energy conditions, NEC, DEC's are satisfied, while infringement of SEC accelerates the expansion of the universe. Moreover, it observed that $n = 2$ is the best fit for the present model, and for various values of ν , the $r - q$ and $r - s$ planes have been studied. Finally, the LRS Bianchi type-I cosmological model obtained, and is compatible with the recent cosmological observational data. This study has been done in collaboration with K. Sri Kavya.

Viscous string anisotropic cosmological model in scalar tensor theory

We investigate the spatially homogeneous and anisotropic Kantowski-Sachs spacetime in the presence of viscous string and new holographic dark energy cosmological model in Saez-Ballester scalar tensor theory. It is found that the density (ρ) of new holographic dark energy is positive, and pressure (p) of the new holographic dark energy is negative. The EoS parameter (ω) shows phantom behaviour. The physical and geometrical



aspects of the statefinder parameters (r, s) and $\omega - \omega'$ plane are also discussed. This work is done in collaboration with V. Uma Maheswara Rao, Gebresilessic Behela, and K. Sri Kavya.

Rashmi Uniyal

Deflection of light by a rotating black hole surrounded by quintessence

We present a detailed analysis of a rotating black hole surrounded by “quintessence”. This solution represents a fluid with a constant equation of state w , which can, for example, describe an effective warm dark matter fluid around a black hole. We clarify the conditions for the existence of such a solution and study its structure by analyzing the existence of horizons as well as the extremal case. We show that the deflection angle produced by the black hole depends on the parameters (c, w) , which need to obey the condition $cw < 0$, because of the weak energy condition, where c is an additional parameter describing the hair of the black hole. In this context, we found that for $w \simeq 0.1$ (consistent with warm dark matter) and $c < 0$, the deviation angle is larger than that in the Kerr spacetime for direct and retrograde orbits. We also derive an exact solution in the case of $w = -1/3$. This work done is in collaboration with Prateek Sharma, Hemwati Nandan Radouane Gannouji, and Amare Abebe.

Sudhaker Upadhyay

Soft-collinear effective theory: BRST formulation

We provide a BRST formalism for the soft collinear effective theory describing interactions of soft and collinear degrees of freedom in the presence of a hard interaction. In particular, we develop a BRST symmetry transformation for SCET theory. We further generalize the BRST formulation by making the transformation parameter field dependent. This establishes a mapping between several SCET actions consistently when defined in different gauge conditions. In fact, a definite structure of gauge-fixed actions corresponding to any particular gauge condition can be generated for SCET theory using this formulation. This work is done in collaboration with Bhabani P. Mandal.

Time dependent dark energy and the thermodynamics of many-body systems

We study the thermodynamics and statistics of the galaxies clustering affected by the dynamical dark energy. We consider two important dark energy models based on time dependent equation of state, to evaluate the gravitational partition function. In the first model, we consider barotropic dark energy with time dependent equation of state. However, in the second model, we consider various kinds of Chaplygin gas equation of state, which originally introduced by string theory. We calculate, analytically and numerically, the thermodynamic quantities in canonical and grand canonical ensembles. We investigate the validity of the second law of thermodynamics for the total system of clustering of galaxies and dynamical dark energy. We finally evaluate the galaxy-galaxy correlation function and compare our model with Peebles power law, and find that the model based on generalized Chaplygin gas may yields to more agreement with observations. This work is done in collaboration with Behnam Pourhassan.

Anisul Ain Usmani

Study of nuclear matter properties for hybrid EoS

We study the nuclear matter properties like symmetry energy, slope parameter, curvature, skewness and incompressibility for hybrid EoS. The hybrid EoS is constructed by combining the hadron phase with the quark phase. For the hadron phase, we use the recently proposed effective-field-theory motivated relativistic mean-field model (E-RMF) with different parameter sets. For the quark phase, we employ the simple Massachusetts Institute of Technology Bag model with different Bag constants. The mixed phase formed by the hadronquark phase transition is studied using the Gibbs construction. The nuclear matter properties for hybrid EoS are calculated and their variation with the Bag constant is determined. Star matter properties like mass and radius are also calculated for the obtained EoS. This work is done in collaboration with Ishfaq A. Rather, and Suresh K. Patra.

Effect of inner crust EoS on neutron star properties

The neutron star maximum mass, and the radius are investigated within the framework of the



relativistic mean-field (RMF) model. The variation in the radius at the canonical mass, $R_{1.4}$, using different inner crust equation of state (EoS) with different symmetry energy slope parameter is studied. It is found that although the NS maximum mass, and the corresponding radius do not vary much with different inner crust EoSs, the radius and the tidal deformability at $1.4M_{\odot}$ vary with the different choice of crust EoS, and variation of about 1-2 km is seen in the radius at the canonical mass. For non-unified EoSs, the crust with a low symmetry energy slope parameter produces a low NS radius at the canonical mass. The properties of maximally rotating neutron stars are also studied. The variation in the radius of rotating star at the canonical mass $1.4M_{\odot}$ is also seen with the slope parameter. Similar to the static neutron star, the radius at $1.4M_{\odot}$ of rotating neutron star is affected by slope parameter of the inner crust. Other important quantities like moment of inertia, frequency, rotational kinetic energy to gravitational energy ratio are also calculated. The variation in these quantities with the crust slope parameter is found to be more proportional to the mass and the radius of NS. This work is done in collaboration with Ishfaq A. Rather, and Suresh K. Patra.

Nilkanth D. Vagshette and Madhav K. Patil

Imaging and photometric studies of NGC 1316 (Fornax A) using Astrosat/UVIT

Imaging and photometric studies of the radio galaxy NGC 1316 (Fornax A) using high spatial resolution near-ultraviolet (NUV) and far-ultraviolet (FUV) imaging telescopes of the first Indian multi-wavelength space observatory *AstroSat* has been presented. The residual maps of UV emission obtained from the subtraction of smooth models witness peculiar features within the central few kpc (1-2 kpc) region. The spatial correspondence between the radio emission maps and FUV imaging study reveal that the UV emitting sources are displaced away from the centre by the AGN outburst (radio jet). The presence of rims and clumpy structures in the outskirts of this galaxy delineate that the galaxy has acquired a large fraction of gas through merger-like events and is still in the process of settling. The estimates of the star formation rates (SFR) using FUV and NUV luminosities are found to be $0.15 M_{\odot} \text{yr}^{-1}$ and

$0.36 M_{\odot} \text{yr}^{-1}$, respectively, and provide the lower limit due to the screen effect. The estimated lower rates of SFR in this galaxy probably represent its quenching due to the AGN driven outflows emanating from the central engine of NGC 1316. This work is done in collaboration with Sachindra Naik, and Neeraj Kumari.

Murli M. Verma

Light deflection angle through velocity profile of galaxies in $f(R)$ model

We explore a new realisation of the galactic scale dynamics via gravitational lensing phenomenon in power-law $f(R)$ gravity theory of the type $f(R) \propto R^{1+\delta}$ with $\delta \ll 1$ for interpreting the clustered dark matter effects. We utilize the single effective point like potential (Newtonian potential + $f(R)$ background potential) obtained under the weak field limit to study the combined observations of galaxy rotation curve beyond the optical disk size and their lensing profile in $f(R)$ frame work. We calculate the magnitude of light deflection angle with the characteristic length scale (because of Noether symmetry in $f(R)$ theories) appearing in the effective $f(R)$ rotational velocity profile of a typical galaxy with the model parameter, $\delta \approx, O(10^{-6})$ constrained in previous work. For instance, we work with the two nearby controversial galaxies NGC 5533 and NGC 4138 and explore their galactic features by analysing the lensing angle profiles in $f(R)$ background. We also contrast the magnitudes of $f(R)$ lensing angle profiles and the relevant parameters of such galaxies with the generalised pseudo-isothermal galaxy halo model and find consistency. This work is done in collaboration with Bipin K. Sharma, and Bal K. Yadav.



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(b) PROCEEDINGS

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38. Vishal Goyal, and **Sandeep Sahijpal** (2021) *Role of impact-induced heating in early lunar-core formation*, Indian Planetary Science Conference, PRL, Ahmedabad, February 25 – 26, 2021.
39. Anuj Gupta, and **Sandeep Sahijpal** (2021) *The evolution of the galactic dust in the solar neighbourhood*, Indian Planetary Science Conference, PRL, Ahmedabad, February 25 – 26, 2021.
40. Tejpreet Kaur, and **Sandeep Sahijpal** (2021) *Short lived radionuclides (SLRs) in the early solar system*, Indian Planetary Science Conference, PRL, Ahmedabad, February 25 – 26, 2021.
41. H. V. Ragavendra, Debika Chowdhury, and **L. Sriramkumar** (2020) *Unique contributions to the scalar bispectrum in 'just enough inflation'*, Procds. Workshop on Frontiers in High Energy Physics, University of Hyderabad, October 14 – 17, 2019, (Eds.) A. Giri, and R. Mohanta (Springer, Singapore), 39 [arXiv:1906.03942].
42. Vineet K. Mannaday, and **Parijat Thakur** (2020) *Exploring the existence of an additional planet in the hot-Jupiter extra-solar planetary system TrES-5*, International Conference on Exoplanets, College of Natural and Agriculture Sciences, Riverside, CA, USA, September 14 – 15, 2020.
43. Vineet K. Mannaday, and **Parijat Thakur** (2020) *Exploring transit timing variation of extra-solar planet TrES-5b through follow-up observations using the 2.0m HCT*, International Conference on HCT20 Science, IIA, Bengaluru, September 29 – 30, 2020.



44. Swadesh Chand, and **Parijat Thakur** (2021) *AstroSat observation of 2016 outburst of H 1743-322: Spectral and timing results*, International Conference on Five Years of AstroSat, ISRO, Bengaluru, January 19 – 21, 2021.

(c) PATEND

B. Sarkar, and **Anirud Pradhan** (2020) *Artificial intelligence based automated stereotactic radio therapy and radiosurgery treatment plan*, Official J. Patent Office, Issue No. **43**, 54257.

(d) BOOKS

Mohit K. Sharma, and **Suresh Chandra** (2020) *Numerical Methods and Data Analysis*, I.K. International Pvt. Ltd., New Delhi (ISBN: 978-93-86768-51-3).

K. T. Bibish Kumar, Sunil John, K. M. Muraleedharan, and **R. K. Sunil Kumar** (2021) *Linguistically Involved Data-Driven Approach for Malayalam Phoneme-to-Viseme Mapping* (Chapter 6), Applied Speech Processing: Algorithms and Case Studies, (Ed.) Nilanjan Dey, 117. Academic Press.

Farook Rahaman (2021) *The General Theory of Relativity: A Mathematical Approach*, Cambridge University Press (ISBN: 9781108936903).

(e) AWARDS AND HONOURS

Aru Beri

Royal Society Newton International Alumni Fellowship, October 2020.

Mehedi Kalam

Member, International Astronomical Union.

Smriti Mahajan

DST's Augmenting Writing Skills for Articulating Research (AWSAR), 2020 (Post-Doctoral Category).

Bivudutta Mishra

Fellow, Institute of Mathematics and Applications, UK.



Anirudh Pradhan

Top 2% World Scientists, based on the survey by Mendeley Scientific Organization (Stanford University, USA) 2020 in Nuclear and Particle Physics: (i) World Ranking: 3014 (ii) Indian Ranking: 56.

Farook Rahaman

Top 2% World Scientists, based on the survey by Mendeley Scientific Organization (Stanford University, USA) 2020 in Nuclear and Particle Physics.

Umesh K. Sharma

Young Scientist, Forum for Interdisciplinary Research in Mathematical Sciences, India, 2020.

Murli M. Verma

Visiting Scientist, Theory Department, CERN.

Membership Affiliation(s) within the IAU for the following: Division C: Education, Outreach and Heritage; Division D: High Energy Phenomena and Fundamental Physics; Division J: Galaxies and Cosmology; Commission C1: Astronomy Education and Development; Commission C2: Communicating Astronomy with the Public; Commission C4: World Heritage and Astronomy; Commission D1: Gravitational Wave Astrophysics; Inter-Commission C1-C3-C4 Working Group: Archaeo-astronomy and Astronomy in Culture; and Division D Working Group: Supernovae.



Department of Physics, Cooch Behar Panchanan Barma University, Cooch Behar

(Coordinator: Ranjan Sharma)

Areas of Research

- Theoretical Astrophysics and Cosmology
- Gravitational Physics.

Currently, two faculty members and ten research scholars are engaged in the theoretical investigation of many topical issues of astrophysics and cosmology. It is noteworthy that the current post-graduate syllabus of the department includes the General Relativity course (2.5 credit) as one of the elective papers. The department also offers Astrophysics and Cosmology courses (15 credit) as special papers to its 4th semester PG students. Kanak Saha (IUCAA) has been appointed as a Visiting Professor at the ICARD, Department of Physics, CBPBU, and has been delivering lectures on Astrophysics and Cosmology courses.

Publications using ICARD Facilities

- Suntharalingam Thirukkanesh, Ranjan Sharma, and Shyam Das (2020) *Model of a static spherically symmetric anisotropic fluid distribution in paraboloidal spacetime admitting a polytropic equation of state*, EPJP, **135**, 629.
- Shyam Das, Ranjan Sharma, Koushik Chakraborty, and Lipi Basky (2020) *Anisotropic compact stellar model of embedding class-I satisfying Karmarkar's condition in Vaidya and Tikekar spheroidal geometry*, GReGr, **52**, 101.
- Kalikkududy Komathiraj, and Ranjan Sharma (2020) *Electromagnetic and anisotropic generalization of a plethora of well-known solutions describing relativistic compact objects*, Ap&SS, **365**, 181.
- Kalikkududy Komathiraj, and Ranjan Sharma (2020) *Exact solution for an anisotropic star admitting the MIT Bag model equation of state*, J. Sci.-FAS-SEUSL, **01(01)**, 22 [ISSN:2738-2184].
- Koushik B. Goswami, Anirban Saha, and Pradip K. Chattopadhyay (2020) *New class of relativistic anisotropic strange star in Vaidya-Tikekar model*, Ap&SS, **365**, 141.
- Ranjan Sharma, Naresh K. Dadhich, Shyam Das, and Sunil D. Maharaj (2021) *An electromagnetic extension of the Schwarzschild interior solution and the corresponding Buchdahl limit*, EPJC, **81**, 79.



- Shyam Das, Bikash C. Paul, and Ranjan Sharma (2021) *Gravitational collapse of anisotropic stars*, InJPh [arXiv: 2012.14084].
- Kalikkuddy Komathiraj, and Ranjan Sharma (2021) *Generating new class of exact solutions to the Einstein-Maxwell system*, EPJP, **136**, 352.
- Kunal Labar, Amit Shankar, Mahesh Ram, Amel Laref, and Ranjan Sharma (2021) *Novel half-metallicity in Y- type equiatomic quaternary Heusler alloys $X\text{FeCrAl}$ ($X = \text{Rh}, \text{Pd}, \text{and Pt}$)*, JPCS, **156**, 110119.

Outreach Programmes

- Ranjan Sharma, and Pradip K. Chattopadhyay have participated as invited speakers in the International webinar entitled: Recent Advancements in Plasma Science and Astrophysics, organized by the Department of Physics, Alipurduar College, West Bengal, on July 8, 2020.

Pradip K. Chattopadhyay has attended the 40th International Conference on High Energy Physics 2020 held online at Prague, Czech Republic, and delivered a talk on August 25, 2020.



Department of Physics and Astrophysics, University of Delhi

(Coordinator: T.R. Seshadri)

Areas of Research

- Astrophysical and Cosmological Magnetic Fields
- Fast Radio Bursts
- Modified Theories of Gravity and their Cosmological Implications
- Late Time Acceleration of the Universe
- Study of Carbonaceous Aerosols in the Atmosphere in Central Himalayas

The combined effect of a non-standard baryon dark matter interaction has been investigated. It has been shown that the y -parameter of the CMB can be significantly enhanced in the presence of both these effects (Arun K. Pandey, Sunil Malik, and T.R. Seshadri).

The data that has been obtained through an observational proposal to VLA to study cluster magnetic fields is being continued (Sunil Malik, Venkatesh Ramakrishnan, Ruta Kale, Hum Chand, Bidisha Bandyopadhyay, and T.R. Seshadri)

It is shown that the evolution of baryon temperature and ionization fraction get modified due to the presence of helical magnetic fields. These in turn lead to modifications in the CMB temperature and polarization anisotropy (Sandhya Jagannathan, Ramkishor Sharma, and T.R. Seshadri).

To constrain galaxy parameters and cosmic curvature, the distance ratio data from a recently compiled database of 161 galactic scale strong lensing systems modelled as an extended power-law have been used. Further, using time-delay measurements and distance sum rule, constraints have been placed on the curvature parameters (Darshan Kumar, Deepak Jain, Shobhit Mahajan, Amitabha Mukherjee, and Nisha Rani).

A systematic statistical analysis has been carried out to study the correlations among various physical quantities associated with the FRBs belonging to the different categories (Nidhi Saini, and Patrick D. Gupta).

The possibility of $f(R)$ models to the observed accelerated expansion of the Universe is being investigated. In particular, generation of cosmology with a bounce using such models is being studied (Manjeet Kaur, Debajyoti Choudhury, and T.R. Seshadri).



Mass Absorption Cross-section (MAC) of light to Black Carbon Aerosol concentration in the atmosphere is an important parameter. The importance of using a site specific MAC value has been investigated and it is shown that otherwise, the radiative forcing in the atmosphere could have an error up to 24 percent.

Lectures/Talks

No.	Date	Speaker	Affiliation	Title
1	27-04-2020	Suprit Singh	UNB, Canada, and IIT, Delhi	<i>About processes - Natural and artificial</i>
2	28-04-2020	Rahul Sharma	Delhi University	<i>The energy spectrum of neutron star X-ray binaries</i>
3	04-05-2020	Arpan Das		<i>AMUSE-ing supermassive black holes in nuclear star cluster</i>
4	11-05-2020	Sunil Malik	Delhi University	<i>Probing magnetic fields in high-z galaxies using rotation measure of quasars</i>
5	12-05-2020	Shantanu Rastogi	DDU Gorakhpur University	<i>Molecular astrophysics</i>
6	18-05-2020	Parul Janagal	IIT, Indore	<i>Sub-pulse drifting in pulsars</i>
7	19-05-2020	Deepak T. Nair	Regional Centre for Biotechnology, Faridabad	<i>An overview of the COVID-19 pandemic</i>
8	25-05-2020	Pranjal Trivedi	Hamburg University, Germany	<i>Primordial magnetic fields and the early universe dynamo</i>
9	26-05-2020	Nissim Kanekar	NCRA, Pune	<i>Cold gas at high redshifts</i>
10	01-06-2020	Sapna Mishra	ARIES, Nainital	<i>A detailed study of broad absorption line quasars</i>
11	08-06-2020	Raya	ARIES, Nainital	<i>The possible association between fast radio bursts and superluminous supernovae</i>



12	09-06-2020	Saloni Deepak	Delhi University	<i>Magnetic field of the milky way from Faraday rotation of pulsar signals</i>
13	15-06-2020	Aditi Agarwal	RRI, Bengaluru	<i>Blazars through multi-wavelength eyes</i>
14	16-06-2020	Dipankar Banerjee	ARIES, Nainital	<i>Long term study of the Sun using Kodaikanal digitised archive</i>
15	21-06-2020	Subramanian Annapurni	IIA, Bengaluru	<i>UVIT and beyond I: Blue straggler stars - understanding their formation using UVIT</i>
16	29-06-2020	Buddhachandra Khundrakpam	McGill University, Canada	<i>Understanding brain development: Implications for neuro-developmental disorders</i>
17	06-07-2020	Ramkishor Sharma	IUCAA	<i>Inflationary magnetogenesis</i>
18	14-07-2020	N, Panchapakesan	Formerly from Delhi University	<i>Some recent news in astrophysics and cosmology</i>
19	20-07-2020	Akshay Rana	Delhi University	<i>Statistical investigation of cosmological assumptions and outcomes.</i>
20	26-07-2020	Shalabh Gautam	IUCAA	<i>The hyperboloidal numerical evolution of a good-bad-ugly wave equation</i>
21	04-08-2020	Priyanka Jalan	ARIES, Nainital	<i>Probing the environment of high-z quasars using the proximity effect in projected quasar pairs</i>
22	10-08-2020	Vidushi Sharma	IUCAA	<i>Probing the emission mechanism of Gamma-Ray Bursts</i>



23	24-08-2020	Priyanka Srivastava	ARIES, Nainital	<i>Tiny carbon bombs in the atmosphere: An insight into the world of carbonaceous aerosols</i>
24	31-08-2020	Akanksha Kapahtia	IIA, Bengaluru	<i>Prospects of constraining the epoch of reionization using morphological descriptors</i>
25	07-09-2020	Priyanka Jalan	ARIES, Nainital	<i>Quasar sightlines: More the merrier!</i>
26	14-09-2020	Priya Goyal	IIA, Bengaluru	<i>Weak gravitational lensing effects on the CMB</i>
27	21-09-2020	Samudrajit Thapa	University of Potsdam, Germany	<i>Deciphering diffusion using Bayesian inference and large deviation theory</i>
28	29-09-2020	Abhishek Paswan	IUCAA	<i>The detection of Lyman continuum emitters with UVIT AstroSat and other UV satellites</i>
29	05-10-2020	Nidhi Saini	Delhi University	<i>Fast radio bursts and their mysteries</i>
30	06-10-2020	Jasjeet Bagla	IISER, Mohali	<i>Atomic Hydrogen content of galaxies at high redshifts.</i>
31	13-10-2020	P. Sreekumar	ISRO, Bengaluru	<i>Opportunities in space astronomy research</i>
32	19-10-2020	Prerna Rana	IIA, Bengaluru	<i>A geometric origin for temporal properties of black hole systems</i>
33	27-01-2021	Amit Setha	Australian National University	<i>Magnetic fields in elliptical galaxies</i>
34	10-03-2021	A. Gopakumar	TIFR, Mumbai	<i>Blazar OJ287 and its nano-Hertz GW emitting massive BH binary central engine</i>
35	24-03-2021	Ananda Sengupta	IIT, Gandhinagar	<i>Unveiling the spectrum of inspiralling binary black holes</i>



Publications using ICARD Facilities

- *Darshan Kumar, Deepak Jain, Shobhit Mahajan, Amitabha Mukherjee, and Nisha Rani (2021) Constraining cosmological and galaxy parameters using strong gravitational lensing systems, PhRvD, **103**, 063511.*
- *Arun K. Pandey, Sunil Malik, and T. R. Seshadri (2021) Implication of baryon-dark matter interaction on IGM temperature and tSZ effect with magnetic field, MNRAS, **500**, 643.*

*Sandhya Jagannathan, Ramkishor Sharma, and T. R. Seshadri (2021) Imprints of the post-recombination dissipation of helical magnetic field on the cosmic microwave background radiation, IJMPD, **30**, 2050122*



Department of Physics, DDU Gorakhpur University

(Coordinator: Shantanu Rastogi)

Areas of Research

- Infrared Observations of Stars
- Circumstellar and Interstellar Medium
- Molecules of Astrophysical Importance
- Star Clusters
- Atmospheric Aerosols
- Trace Gases in Planetary Atmospheres

The members (Amit Pathak, BHU, and Shantanu Rastogi, DDUGU) have studied various aspects of astrophysical mid infrared emission features, and the possible carrier polycyclic aromatic hydrocarbon (PAH) molecules. Near-IR observations on late type stars are carried out using Devasthal Optical Telescope, ARIES, Nainital (Shantanu Rastogi, and Brijesh Kumar, ARIES, Nainital). Theoretical studies on chemical pathways to formation of pre-biotic molecules in interstellar medium are being done (Alka Mishra, LU). Numerical codes are developed for analysis of AstroSat observations (Sanjay Pandey, LBS (PG) College, Gonda). Continuous monitoring of atmospheric aerosols at Gorakhpur is being carried out (Shantanu Rastogi).

Colloquium/Lecture (online)

- Colloquium on *Molecular astrophysics*, by Shantanu Rastogi, May 12, 2020 (in collaboration with ICARD, Delhi).
- Special lecture on *Black holes: The 2020 Nobel prize in physics*, by Ajit Kembhavi, October 23, 2020.

Publications using ICARD Facilities

- Gauri Devi, Mridusmita Buragohaina, and Amit Pathak (2020) *DFT study of five-membered ring PAHs*, P&SS, **183**, 104593.



- Rahul K. Anand, Shantanu Rastogi, Brijesh Kumar, Arpan Ghosh, Saurabh Sharma, et al. (2020) *Detection of PAH and nbL features in planetary nebulae NGC 7027 and BD +30° 3639 with TIRCAM2 instrument on 3.6 m DOT*, JApA, **41**, 27.
- Keshav K. Singh, Poonam Tandon, Alka Misra, Shivani, Manisha Yadav, et al. (2021) *Quantum chemical study on the formation of isopropyl cyanide and its linear isomer in the interstellar medium*, IJAsB, **20(1)**, 62.
- Mukunda M. Gogoi, S. Suresh Kumar, B.S. Arun, K. Krishna Moorthy, ..., Shantanu Rastogi, et al. (2021) *Response of ambient BC concentration across the Indian region to the nation-wide lockdown: Results from the ARFINET measurements of ISRO-GBP*, CSci, **120**, 341.

Outreach Programmes

- Sanjay K. Pandey (Translated into Hindi, Official Summaries of LIGO Science <https://www.ligo.org/science/Publication-O3aCatalog/translations/science-summary-hindi.pdf>, also at <https://www.ligo.org/science/outreach.php>.)

Annular solar eclipse watch organized at DDUGU on June 21, 2020. Eclipse was seen through filters, telescopes, reflecting pin-hole camera, etc.



Department of Physics, Gurukula Kangri University, Haridwar

(Coordinator: Hemwati Nandan)

Areas of Research

- Classical Gravity
- Cosmology

The physics of two particles with different energies colliding near the horizon of a static spherically symmetric black hole is explored in view of the Bañados, Silk, and West (BSW) scenario. Surprisingly, we observed that even for the static spherically symmetric (i.e., Schwarzschild like) black holes, it is possible to obtain an arbitrarily high centre of mass energy from the two test particles colliding near the horizon of a black hole, if one fine-tunes the parameters of geodesic motion.

The connection between gravitational dynamics of the horizon and thermodynamics for the case of charged radiating rotating axially symmetric black holes is studied in detail, and it is shown that Einstein field equations near apparent horizon can be interpreted in the form of thermodynamic laws.

Lectures

- *Aditya mission, Government of India*, by Arvind Ranade (Vigyan Prasar, New Delhi).
- *The physics of stars*, by T. R. Seshadri, (University of Delhi).
- *The ultimate cosmic chakravayuh: Black holes*, by Patrick D. Gupta (University of Delhi).
- *Gravitation interaction in daily life situations*, by Padma Sri Professor H. C. Verma, (Formerly from IIT, Kanpur).
- *Recent discoveries in gravity and cosmology*, by M. Sami, (CTP, JMI, New Delhi).

Publications using ICARD Facilities

- Eva Hackmann, Hemwati Nandan, and Pankaj Sheoran (2020) *Particle collisions near static spherically symmetric black holes*, PhLB, **810**, 135850.
- Uma Papnoi, and Sushant G. Ghosh (2020) Thermodynamics from field equations for charged radiating rotating black hole near horizon, IJMPA **35(19)**, 2050092.



Honours/Distinctions/Awards

Hemwati Nandan has been appointed as Board Member of the School of Physical and Material Sciences, Himanchal Pradesh Central University, for three years, starting June 24, 2020.



Department of Physics, Cochin University of Science and Technology, Kochi

(Coordinator: Titus K. Mathew, and Co-coordinator: Charles Jose)

Areas of Research

- Dark Energy Models
- Emergent Gravity Paradigm
- Cosmological Structure Formation

Holographic Ricci dark energy evolving through its interaction with dark matter is a natural choice for the running vacuum energy model. We have analyzed the relative significance of two versions of this model in the light of SNIa, CMB, BAO and Hubble data sets using the method Bayesian inferences. The first one, model 1, is the running holographic Ricci dark energy (rhrde) having a constant additive term in its density form, and the second one is, model 2, having no additive constant, instead the interaction of rhrde with dark matter is accounted through a phenomenological coupling term. The Bayes factor of these models in comparison with the standard Λ CDM have been obtained by calculating the likelihood of each model for four different data combinations, SNIa (307) + CMB + BAO, SNIa (307) + CMB+ BAO + Hubble data, SNIa (580) + CMB + BAO, and SNIa (580) + CMB + BAO + Hubble data. Suitable flat priors for the model parameters has been assumed for calculating the likelihood in both cases. Our analysis shows that, according to the Jeffreys scale, the evidence for Λ CDM against both is very strong as the Bayes factor of both models are much less than one for all the data combinations.

The special expansion of the universe could be described as a tendency for satisfying holographic equipartition, which inevitably demands the presence of dark energy. We explore whether this novel idea proposed by Padmanabhan give any additional insights into the nature of dark energy. In particular, we obtain the constraints imposed by the law of emergence on the equation of state parameter, ω . We also present a thermodynamic motivation for the obtained constraints on ω . Further, we explicitly prove the feasibility of describing a dynamic dark energy model through the law of emergence. Interestingly, both holographic equipartition and the entropy maximization demands an asymptotically de Sitter universe with $\omega \geq -1$, rather than a pure cosmological constant.

Structure formation in cosmology is still an active area of research and has been made considerable progress in this field.

Publications using ICARD Facilities

- P.B. Krishna, and Titus K. Mathew (2020) *Does holographic equipartition demand a pure cosmological constant?*, MPLA, **35(40)**, 2050334.



Outreach Programmes

The ICARD has established a sky observation centre with a newly installed 10-inch astronomical telescope. The telescope is having an automatic tracking system. Students from CUSAT, and from across Kerala, and also the public were able to use this newly acquired facility to watch and study the night sky.



Department of Physics, University of Calicut, Kozhikode

(Coordinator: C.D. Ravikumar)

Area of Research

- Galaxy Formation and Evolution
- Compact Objects

Seminars (Online)

- *Quenching of star formation in nearby field early-type galaxies*, by K. Sruthi, on August 19, 2020.
- *Study of central intensity ratio in nearby Seyfert galaxies*, by K.T. Vinod, on August 26, 2020.
- *Jet power estimation of PKS 2155-304 using the minimum emitted electron energy*, by Sitha K. Jagan, on September 30, 2020.
- *Does radiative loss decide the characteristic emission of blazar MKN 421?*, by C. Baheerja, on October 28, 2020.
- *Blazar spectral modelling*, by K.K. Habeeb Rahman, on November 18, 2020.

Publications using ICARD Facilities

- K.T. Rethika, C.D. Ravikumar, and Vishnu M. Bannur (2021) *Heavy quarkonium properties at finite temperature in strongly coupled quark gluon plasma*, FBS, **62(1)**, 10 [doi:10.1007/s00601-021-01592-6].
- K. Sruthi, and C.D. Ravikumar (2021) *Study of central intensity ratio of early-type galaxies from low-density environment*, MNRAS, **500**, 1343 [doi:10.1093/mnras/staa3334].



**School of Physical Sciences,
Swami Ramanand Theerth Marathwada University, Nanded**
(Coordinator: Madhav K. Patil)

Areas of Research

- AGN Feedback in Galaxy Clusters
- Soft X-ray Excess Emission from Type 1 AGNs
- Correlation between X-ray vs Optical/UV Variability of AGNs
- X-ray Binary Sources (XRBs)
- Dust Extinction and Multiphase ISM in Early-type Galaxies

Researchers at SRTMU are involved in investigating and quantifying the power injected by the radio jets into the ICM by measuring pdV work of the cavities, and checking their balance with that quantified by studying radio jets. This study involves analysis of high resolution X-ray data from Chandra X-ray Telescope and multi-frequency radio data acquired using uGMRT. Collaborators in this study are Somak Raychaudhary (IUCAA), Dharam V. Lal (GMRT), Ishwar Chandra (NCRA), and Sachindra Naik (PRL).

Systematic study using the most advanced observing facilities like, Chandra and XMM-Newton, has shown that the soft excess emission is a smooth continuum component rather than a blend of emission/absorption features.

It is obvious that there must be a coupling between the disk and corona emission. Researchers from SRTMU, with Ranjeev Misra and Gulab C. Dewangan (both from IUCAA), using the simultaneous observing capabilities at Optical/UV and X - ray wavelengths of the space-born telescopes like AstroSat, XMM-Newton, and Swift are involved in investigating the inter-band variability properties of AGN.

ICARD – SRTMU is involved in the study of XRB population in star forming galaxies. This study is based on the X-ray data acquired using the LAXPC onboard of AstroSat, and is carried in collaboration with Ranjeev Misra and Gulab C. Dewangan.

The School is also involved in the study of multiphase ISM in early-type galaxies in collaboration with S. K. Pandey (PRSU, Raipur). This study is based on multi-frequency observations of early-type galaxies selected from different environments.



Publication using ICARD facilities

- Nilkanth D. JApA, 42, 34 Vagshette, Sachindra Naik, Neeraj Kumari, and Madhav K. Patil (2021) Imaging and photometric studies of NGC 1316 (Fornax A) using AstroSat/UVIT, [[arXiv: 2101.05190](https://arxiv.org/abs/2101.05190)].

Outreach Programmes

Public Lectures by Madhav K. Patil

- *Solar eclipse and its implications* (online), organised by Yogeshwari Mahavidyalaya, Ambejogai, on the occasion of the Partial Solar Eclipse on June 21, 2020.
- Inaugural address on the occasion of One Month Countrywide National Science Students Development Programme for Under-Graduate Students, jointly organized by SRTM University, and NSB Science College, Nanded, during July 27 – August 26, 2020.
- Keynote address in the Workshop on Revision of BSc Third Year CBCS Curriculum Development, jointly organized by School of Physical Sciences, SRTM University, and Yeshwant Mahavidyalaya, Nanded, on January 27, 2021.
- *Optical astronomy – Data analysis*, in the 2nd Winter School in Observational Astronomy, organized by MPCST, IIT, Indore, and IIA, Bengaluru, on February 8, 2021.
- *Taryanche vishwa – World of stars* (in Marathi), as a part of the National Science Day celebration of Parbhani Astronomical Society, on February 27, 2021.

The world of stars (online), under the DST-Star College Programmes, organized by Shivaji Science College, Barshi, on March 23, 2021



School of Studies in Physics and Astrophysics, Pt. Ravishankar Shukla University, Raipur

(Coordinator: Nand K. Chakradhari)

Areas of Research

- Supernovae
- X-ray Binaries
- Galaxies
- Variable Stars

UV-optical photometric and spectroscopic study of supernovae is being carried out by Nand K. Chakradhari, and Shritika Tiwari (Thesis work) in collaboration with G.C. Anupama, Devendra K. Sahu (both from IIA, Bengaluru), and Kuntal Misra (ARIES, Nainital).

Study of chemically peculiar stars/variable stars is being carried out in collaboration with Santosh Joshi (ARIES, Nainital).

Study of central region of lenticular galaxies is being carried out by S.K. Pandey, Mahendra Verma (Thesis work), and Sudhanshu Barway (IIA Bengaluru).

Nand K. Chakradhari has been involved in the co-supervision of (i) Massive O-type and WR stars, Thesis work of Bharti Arora, with Jeewan C. Pandey (ARIES, Nainital), and (ii) Study of GRBs, Thesis work of Ankur Ghosh, with Amitesh Omar and Kuntal Misra (both from ARIES, Nainital).

Outreach Programmes

Invited/Public Lectures

- *Understanding the life of a star*, in the National Webinar, organized by the Department of Physics, Arya Vidyapeeth College, Guwahati, on July 22, 2020.
- *Looking into a star's journey*, in the National Webinar on Mysteries of the Universe, organized by Seth Phool Chand Agrawal College, Nawapara, Rajim on July 23, 2020.
- *Observational studies of SNe Ia with HCT*, at 20 years of Himalayan Chandra Telescope meeting, during September 29 – 30, 2020.



- *Time, seasons, and astrophysics*, organized by Chhattisgarh Vigyan Sabha, Raipur, on December 12, 2020.
- *Understanding the sky and how to observe*, at the workshop organized, by Chhattisgarh Vigyan Sabha, Raipur, for the preparation of Jupiter Saturn Conjunction event, during December 19 – 20, 2020.
- *Constellation, time and season in astrophysics*, at Dhamangaon College, Amravati, on December 23, 2020.
- *The experimental component of astronomy teaching*, at PRSU, Raipur, in ASI 2021 meeting, during February 18 – 23, 2021

Sky Watching Programmes

- *Partial solar eclipse* on June 21, 2020 (annular in north India).
- *Jupiter Saturn conjunction* on December 21, 2020.

Television Programmes

- *Partial solar eclipse*, on June 21, 2020.
- Live interviews were held on the occasion of *Jupiter Saturn conjunction*, on December 21, 2020.

Honours/Distinctions/Awards, etc.

Nand K. Chakradhari has been selected for INSA Visiting Scientist Fellowship 2020 - 21 (extended).



Department of Physics, University of North Bengal, Siliguri

(Coordinator: Bikash C. Paul)

Areas of Research

- Relativistic Astrophysics
- Compact Objects
- Data Analysis of X-ray Sources
- Pulsar
- Non-linear Dynamics
- Cosmology

Computers of the Data Centre are used by the Research Scholars of the department, and the students from Kaziranga University.

Seminars (Online)

- *Introductory astrophysics and cosmology*, on September 16, 2020.
- *Black hole shadow*, by Sushant G. Ghosh, CTP, Jamia Milia Islamia, New Delhi, on March 23, 2021.
- *Recent advances in astrophysics*, during March 24 – 25, 2021.

Publications using ICARD Facilities

- Partha S. Debnath, and Bikash C. Paul (2020) *Observational constraints of emergent universe in $f(R, T)$ gravity with bulk viscosity*, IJGMM, **17**, 2050102.
- Pragati Pradhan, Biswajit Paul, Enrico Bozzo, Chandreyee Maitra, and Bikash C. Paul (2021) *Comprehensive broadband study of accreting neutron stars with Suzaku: Is there a bi-modality in the X-ray spectrum?*, MNRAS, **502(1)**, 1163.
- Arindam Saha, Souvik Ghose, Anirban Chanda, and Bikash C. Paul (2021) *Renyi holographic dark energy in higher dimension cosmology*, AnPhy, **426**, 168403.



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- Sagar Dey, Anirban Chanda, and Bikash C. Paul (2021) *Compact objects in $f(R, T)$ gravity with Finch-Skea geometry*, EPJP, **136**, 228.
 - Partha S. Debnath, and Bikash C. Paul (2021) *Bouncing scenario with causal cosmology*, Ap&SS, **366**, 32.
 - Shyam Das, Bikash C. Paul, and Ranjan Sharma (2021) *Gravitational collapse of anisotropic star*, InJPh [arXiv: 2012.14084].



Department of Physics, Tezpur University

(Coordinator: Rupjyoti Gogoi)

Areas of Research

- Astronomical Observations
- Data Analysis

Webinar/Schools

- *Exploring the life and times of cosmic dust in our local universe*, on November 5, 2020.
- *Fantastic black holes and where to find them*, on November 9, 2020.

Introductory astronomy and astrophysics (online), during January 27 – April 9, 2021.



Department of Physics, Newman College, Thodupuzha

(Coordinator: Joe Jacob)

Areas of Research

- Radio Astronomy
- X-ray Astronomy
- Machine Learning

Four research scholars in the department have been using the ICARD facilities for research.

Workshop

- *Research in astronomy- opportunities and challenges*, during July 9– 10, 2020

Outreach Programme

The landmark discovery of a far away galaxy using the Indian AstroSat Space Observatory (National webinar), on September 28, 2020. This was a joint venture of ICARD, and the Pune Knowledge Cluster

ICARD
INDIAN CENTRE FOR ASTRONOMY RESEARCH AND DEVELOPMENT (ICARD)
NATIONAL WEBINAR

THE LANDMARK DISCOVERY OF A FAR AWAY GALAXY USING THE INDIAN ASTROSAT SPACE OBSERVATORY

2020 SEPT 28
10:45 AM

DR. KANAK SAHA

ICARD DEPARTMENT OF PHYSICS, NEWMAN COLLEGE, THODUPUZHA

Dr. Kanak Saha is an Associate Professor at the Inter-University Centre for Astronomy and Astrophysics (IUCAA) Pune. His primary research is focused on Galaxies: their structure, formation and evolution. His research spans across the study of high-redshift galaxies which are just forming to well-developed galaxies at low redshifts. He took his Ph.D from IISc Bangalore in the year 2008. Prior to joining IUCAA, he had been a postdoc/long-term visitor at different institutes viz., Geneva Observatory (Geneva), Max Planck Institute for Extraterrestrial Physics (Munich), Academia Sinica Institute of Astronomy and Astrophysics (ASIAA), (Taiwan), Theoretical Institute for Advanced Research in Astrophysics (TIARA), (Taipei), RRI, Bangalore, STScI (Baltimore).

ICARD DEPARTMENT OF PHYSICS, NEWMAN COLLEGE, THODUPUZHA

The Department of Physics, Newman College was approved as an ICARD Centre for Astronomy Research and Development (ICARD) in 2016, with an aim to put in a major push for promoting astronomy research and popularization activities in the region. Over the span of a year, the centre has promoted many astronomy-themed workshops and outreach programmes for students in interaction with the starry night. The Department of Physics has been offering IC programmes in physics for the last thirty seven years and IC programmes for the last twenty six years. It is also a research centre of the Massimo Cecchi University from 2020 onwards. These PhDs have been awarded from the Department and last research scholars are working towards their degree. The department has a checked history of promoting scientific temper and attitude in the region.

Dr. Kanak Saha

Dr. Joe Jacob
Coordinator, ICARD

Dr. Theroon Joseph
Principal
Newman College

RESEARCH IN ASTRONOMY- OPPORTUNITIES AND CHALLENGES

ICARD

ICARD DEPARTMENT OF PHYSICS, NEWMAN COLLEGE, THODUPUZHA

The ICARD has been established by the Office of the Principal Scientific Advisor to the Government of India. The aim is to bring together academic, R&D institutions and the industry at Pune and its surrounding regions to address the challenging problems of the region through innovative means, using scientific knowledge and engaging highly skilled human resources. The ICARD will also help in capacity building and promote advanced skills development. All relevant organizations and experts will be partners and consulted to identify sustainable solutions to the problems of the city and improve its feasibility and prosperity.

Dr. Kanak Saha

Dr. Joe Jacob
Coordinator, ICARD

Dr. Theroon Joseph
Principal
Newman College



BALANCE SHEET



33rd
ANNUAL REPORT
2020-21

Funds & Liabilities		PROPERTY & ASSETS	
Rs.	Rs.	Rs.	Rs.
Trusts Funds or Corpus :-		Immovable Properties :- (At Cost)	
Balance as per last Balance Sheet	0	Balance as per last Balance Sheet	75,26,03,406
Adjustment during the year (give details)	0	Additions during the year	14,41,30,864
Schedule No. 6		Less : Sales during the year	
		Depreciation up to date	21,28,43,663
	2,10,40,313	Schedule No. 11	68,38,90,608
Other Earmarked Funds :-		Investments :-	
(Created under the provisions of the trust deed or scheme or out of the income)	9,03,21,070	Note : The market value of the above investment is Rs.	55,80,86,407
Balance as per last Balance Sheet	Opening Balance	Furniture & Fixtures :-	
Grant in Aid - 2 MTR (CAPITAL)	11,90,80,000	Balance as per last Balance Sheet	3,13,52,031
Grant in Aid BUILDING	11,97,49,000	Additions during the year	1,72,040
Capital Grant to the extent of Depreciation Additions during the year	(1,25,19,01,411)	Less : Sales during the year	0
	(15,35,18,709)	Depreciation up to date	31,45,049
Grant in Aid General (Capital) from UGC	2,23,97,47,253	Schedule No. 11	2,83,79,022
Additions during the year	16,78,24,047	Loans (Secured or Unsecured) :	
Less : Subtraction/reversed	10,73,96,321	Good/doubtful	
Schedule No. 7		Loans Scholarships	
	2,30,01,71,979	Other Loans	
Any Other Fund - Project Grants		Advances :-	
Schedule No. 8	32,95,63,752	To Trustees	0
		To Employees and other	3,70,96,347
		To Suppliers/Security Deposits/Prepaid Exp.	2,46,92,558
		To Lawyers	
		To Project and Other Receivables	17,71,247
Loans (Secured or Unsecured) :-		Schedule No. 13	
From Trustees	0	Income Outstanding :-	
From Others	0	Rent	
Liabilities :-		Interest	
For Expenses and other liabilities	10,27,73,875	Other Income	
For Projects and Other Payables	10,90,07,044	Cash and Bank Balances :-	
For Rent & Other Deposits, duties and taxes	12,51,860	(a) In Savings Account with -	
For Sundry Credit Balances	25,50,098	Bank of Baroda	28,50,19,816
Schedule No. 10 & 10 A		In Fixed Deposit Account with -	
Income and Expenditure Account :-		(b) With the Trustee	
Balance as per last Balance Sheet	(45,70,55,270)	(c) With Our Manager	
Less : Appropriation, if any	(2,78,27,715)	Schedule No. 13	
Add : Deficit as per Income and	0	Income and Expenditure Account :-	
Less : Surplus Expenditure Account	1,26,37,118	Balance as per Balance Sheet	
Schedule No. 14		Less : Appropriation, if any	
	(47,22,15,867)	Add : Deficit as per Income and	
		Less : Surplus Expenditure Account	0
Total Rs.....	1,61,88,46,004	Total Rs.....	1,61,88,46,004



As per our report of even date,
For A.H. JOSHI & CO.
Chartered Accountants
FIRM: 112396W

Place : Pune
Dated : 30.06.2021

CA. S. A. Joshi
(Partner)

Membership No. 037772

UDIN: 21037772AAAAWM4853

M. S. Sahasrabudhe
Admin. Officer (Accounts)

N.V. Ashyankar
(Sr. Admin. Officer)

For Inter-University Centre for Astronomy and Astrophysics

Prof. Sonali Raychaudhary
Director / Trustee

Chairperson/Trustee
Governing Board

*This Balance Sheet is as per BPT Format and Charity Commissioner's Instructions



IAUS367: Education and Heritage in the Era of Big Data in Astronomy

The primary goal of the International Astronomical Union Symposium 367 (IAUS 367) held online during December 8 – 12, 2020, was to give a global vision of Education and Heritage in the frame of the goals of the IAU. This was taken into account the Plan 2020 – 2030, and to propose an eventual 'next steps' road map and a global astronomy education agenda for the next decade, while honouring the education from the past.



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