29th वार्षिक अहवाल ANNUAL REPORT 2016-17

IUCAA

अंतर–विश्वविद्यालय केंद्र :
खगोलविज्ञान और खगोलभौतिकी

INTER-UNIVERSITY CENTRE FOR
ASTRONOMY AND ASTROPHYSICS
(An Autonomous Institution of the University Grants Commission)


DEVAYANI

IUCAA

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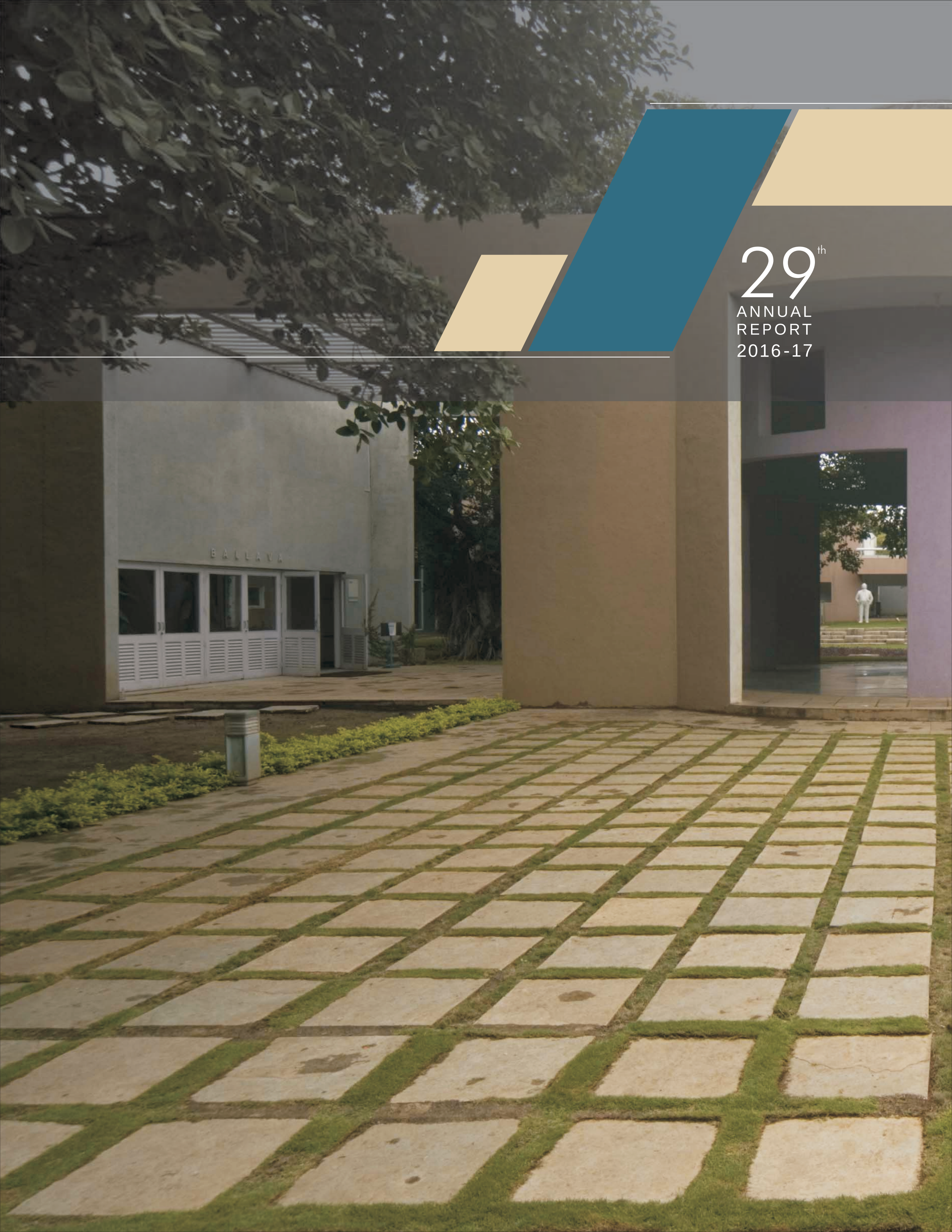

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KARAN KUMAR DATTA


SUKANTA DEB


GURUDATT GAUR


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Durgesh Tripathi

Head, Teaching Programmes
R. Srianand

Dean, Visitor Academic Programmes
Kandaswamy Subramanian

Head, Public Outreach Programmes
Sanjit Mitra

Head, Scientific Meetings
Ranjeev Misra

Head, IRCs, IUCs, and INAADs
Ranjeev Misra

Head, Infrastructural Facilities
Tarun Souradeep

Head, Observing Programmes and SALT
R. Srianand
Ranjan Gupta

Head, Grievance Cell
Kandaswamy Subramanian

DIRECTOR'S REPORT

This has been a year of very intense activity and excitement for researchers at IUCAA. The academic members of IUCAA continue to make significant contributions to research in Astronomy, Astrophysics and related subjects, and to organise and participate in meetings and workshops all over the country and indeed all over the world.

Over the last academic year, ten new research scholars and six new Postdoctoral fellows have joined out Institute, while six IUCAA scholars have obtained Ph.D. degrees. The 93 academic members at IUCAA, including faculty, postdoctoral fellows and students, have published 182 peer-reviewed papers, with a mean impact factor of 5.4. I am very proud of this statistic, since it shows that my colleagues are not just very productive in their research, but they are making a substantial impact on the subject. Even more gratifying is the fact that the 144 Visiting associates of IUCAA, who are faculty members at Indian Universities and Colleges, supported in their research by IUCAA, have published 158 peer-reviewed papers during the same period. This clearly indicates the impact IUCAA has had in promoting and nurturing Astrophysics research at institutions of higher education all over the country.

Following the discovery of gravitational waves during the previous year by the LIGO-VIRGO Consortium, using the two LIGO observatories in the USA, successful detections have continued, in which members of the group built by Professor Sanjeev Dhurandhar in the early 1990s at IUCAA, many of whom are now in charge of their own groups all over the country, continue to play leading roles. The Indian consortium for gravitational wave research, INDIGO, which includes 37 authors of the discovery paper, was also formed and consolidated at IUCAA.

This activity will of course continue to grow, as IUCAA has now assumed the role of one of the apex institutes in charge of building, installing and running the first LIGO detector outside the USA, which will be on Indian soil. IUCAA has led the exercise to select the site for the LIGO-India observatory, and is now actively involved in the acquisition and characterization of the site. The computational infrastructure for current LIGO data reduction, as well as constructing the data-crunching capacity for the future observatory, is also being developed at IUCAA. At the same time, we are in charge of building the human resources for all activities starting from the installation to the scientific operations of LIGO-India. I am proud to say that the UGC has granted us a large number of faculty and technical positions, in this first phase, to augment our capacity to support this prestigious project of National importance.

India's first space-borne multi-wavelength astronomical observatory ASTROSAT was launched by ISRO during 2015-16, and since then, activities with ASTROSAT have been a significant feature of IUCAA's research landscape. This includes scientific and technical contributions to all the payloads on this satellite, and well as the establishment of the ASTROSAT Science Support Cell at IUCAA, supported by ISRO. This provides a unique opportunity for University students and faculty, and IUCAA members and associates, to carry out their scientific research with ASTROSAT. Workshops are being held at regular intervals at IUCAA and elsewhere at colleges and universities to introduce the community to these new opportunities. An excellent team at IUCAA is also building SUIT, a payload for ultraviolet imaging that will be one of the major instruments aboard ISRO's Aditya-L1 mission to study the Sun.

IUCAA is committed to support the teaching of Astrophysics at Colleges and Universities in India. The past year saw several Universities taking the opportunity of the new choice-based system of courses, being encouraged by the UGC, to initiate introductory Astrophysics courses at the undergraduate level in Physics and Science departments of Universities. The teaching of Astrophysics at the Masters level continues to flourish. We will continue to support the design and implementation of such tailor-made teaching activities in Astrophysics at any HE institution in India, and in the process help students get trained for the immense opportunities in Astrophysics opening up in the country.

IUCAA has been at the forefront of fundamental research, and the development of teaching pedagogy, in almost all branches of Astrophysics, Cosmology and Theoretical Physics at the national and international level, for three decades. The world-leading research at IUCAA, and at Indian Universities through the network of IUCAA associates, owes a great deal to the hard-working and talented staff (both core and contractual) working at our institution. I wish to express my sincere gratitude to every one of them, and to our mentors, our Governing Board with Dr. Srikumar Banerjee as Chair, and our Governing Council, with Dr. Ved Prakash (and now Dr. V S Chauhan) as Chair. We sincerely acknowledge the help, advice and support from the University Grants Commission and its officers and staff.

Somak Raychaudhury
Director

Anirban Ain, Sukanta Bose, Sanjeev Dhurandhar, Sharad Gaonkar, Anuradha Gupta, Sanjit Mitra, Nikhil Mukund, Jayanti Prasad and Tarun Souradeep

Milner's Special Breakthrough Prize in Fundamental Physics, shared with LIGO and Virgo Science Collaboration (LVC).

Gruber Prize on Cosmology, shared with LVC.

Sukanta Bose

Science Lead, LIGO - India Project.

Sumanta Chakraborty and Kinjalk Lochan

Honourable Mention in the Gravity Research Foundation essay competition.

Sanjeev V. Dhurandhar

The H.K. Firodia Vigyan Bhushan Award, 2016.

Ajit Kembhavi

Appointed a Vice-President of the International Astronomical Union (IAU) for six years from August 2015.

Jayant V. Narlikar

Felicitated during the 90th Akhil Bharatiya Marathi Sahitya Sammelan, Dombivli, February 4, 2017.

Aseem Paranjape

Selected an Associate of the Indian Academy of Sciences, Bengaluru.

Tarun Souradeep

Elected the President of the Indian Association for General Relativity and Gravitation (IAGRG) for two year from March 2016.

Arunima Banerjee

INSPIRE Faculty Fellowship, Department of Science and Technology, Government of India.

Varun Bhalerao

INSPIRE Faculty Fellowship, Department of Science and Technology, Government of India.

Dipankar Bhattachraya

AstroSat Science Support Cell Grant, ISRO, Bengaluru.

Sukanta Bose, Ajit Kembhavi, Sanjit Mitra and Tarun Soueradeep

Gravitational Waves Data Centre Grant, Navajbai Ratan Tata Trust, Mumbai.

Anuradha Gupta

National Post-doctoral Fellowship, Department of Science and Technology, SERB, Government of India.

Girjesh Gupta

INSPIRE Faculty Fellowship, Department of Science and Technology, Government of India.

Neeraj Gupta

Start-up Research Grant, Department of Science and Technology, Government of India.

Research Grant, Indo-French, CFIPRA.

Indo - South Africa Flagship Programme in Astronomy Grant, NRF, South Africa and Department of Science and Technology, Government of India.

Ajit Kembhavi

NKN - NIC Data Diverse Initiative in Astronomy Grant, Ministry of Electronics and Information Technology, Government of India.

The Raja Ramanna Fellowship - TRACK I, by the Department of Atomic Energy, Government of India.

Sanjit Mitra

Science Toys for Education Grant, Sir Ratan Tata Trust, Mumbai.

The SwarnaJayanti Fellowship, Department of Science and Technology, Government of India.

T. Padmanabhan

J.C. Bose Fellowship, Department of Science and Technology, Government of India.

Aseem Paranjape

Ramanujan Fellowship, Department of Science and Technology, SERB, Government of India.

A.N. Ramaprakash

Thirty Metre Telescope (TMT) Grant, Department of Science and Technology, Government of India.

Resurgent Caltech - IUCAA Collaboration Grant, Infosys Foundation, Bengaluru.

Devasthal Optical Telescope Integral Field Spectrograph (DOTIFS) Grant, Korean Institute of Advanced Studies, Seoul, South Korea.

Wide Area Linear Optical Polarimeter (WALOP) North Grant, Institute of Plasma Physics, Crete, Greece.

Wide Area Linear Optical Polarimeter (WALOP) South Grant, South African Astronomical Observatory, Cape Town.

CIRCE, MIRADAS, Detector Controllers Grant, University of Florida, USA.

Large Binocular Telescope Interferometer Grant, University of Arizona, USA.

RSS - NIR on Southern African Large Telescope Grant, University of Wisconsin, USA.

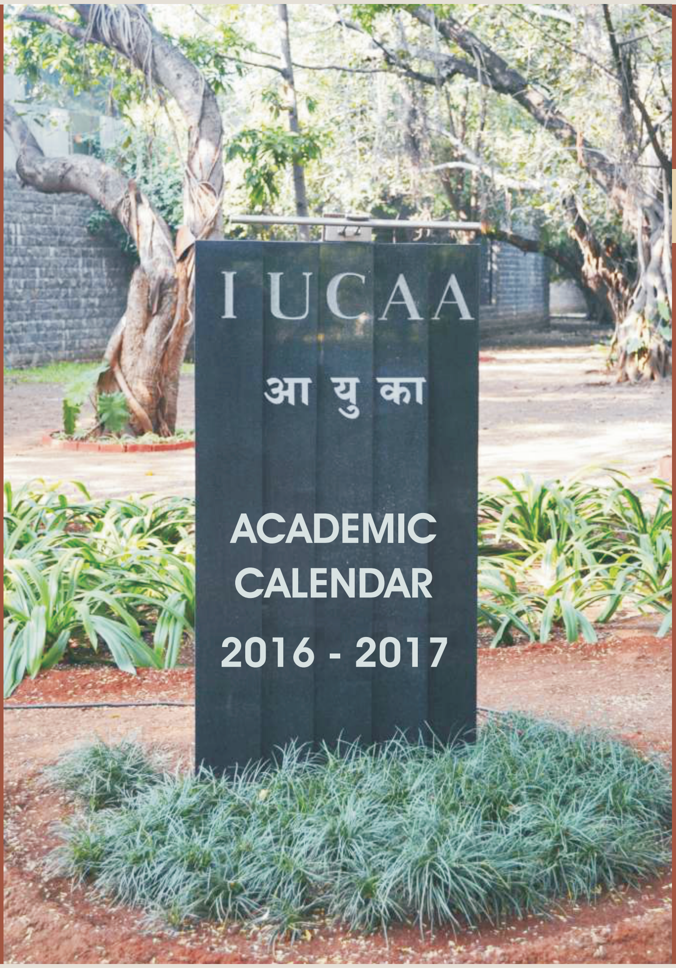
3 D Polarization Mapping of High Galactic Latitude Sky Grant, Caltech, USA.

A.N. Ramaprakash and Durgesh Tripathi

Solar Ultraviolet Imaging Telescope (SUIT) Grant, ISRO Satellite Centre, Bengaluru.

Durgesh Tripathi

Max-Planck Partner Group Research Grant, Max-Planck Society, Germany, and Department of Science and Technology, Government of India.



ANNUAL EVENTS AT IUCAA

2016

April 4 - 15
School Students' Summer Programme

April 25 - May 20
Summer Astronomy Camp

May 16 - July 1
Vacation Students' Programme

December 29
Foundation Day

2017

February 28
National Science Day

EVENTS AT IUCAA

2016

April 5
Kick-off Meeting on India - TMT

May 16 - June 17
Introductory Summer School in Astronomy and Astrophysics
(For College and University Students)

July 13 - 14
Meeting on AstroSat AO Proposal Submission: Guidelines and Technical Issues

August 8 - 10
Workshop on Hands-on Science and Maths
(Funded by the Tata Trusts, Mumbai)

August 16 - 18
Meeting on LIGO - India: The Road Ahead (LITRA - I)

September 29
Science Meet to Commemorate One Year of AstroSat in Orbit

October 17 - 18
Workshop on Hands-on Astronomy

November 24 - 25
IUCAA - South Africa Meeting on Cosmology

December 14 - 23
IUCAA - NCRA Radio Astronomy Winter School

December 19 - 21
Meeting on LIGO - India: The Road Ahead (LITRA - II)

2017

January 2 - 10
Topical Course in Computational Statistics and Astro-Statistics

January 16 - 27
Training School in Optical Astronomy with Large Telescopes

January 30 - February 4
Hands-on Activities in Mathematics and Science

February 13 - 18
Workshop on Data Intensive Science
(Jointly with the Persistent Systems Ltd., Pune)

March 7 - 9
Workshop on Aspects of Gravity and Cosmology

March 27 - 28
Meeting on LIGO - India: The Road Ahead (LITRA - III)

EVENTS OUTSIDE IUCAA

2016

June 26 - 30
Short Term Course on Dynamical Systems: Theory and Applications
At: Indian School of Mines, Dhanbad

July 16 - 17
IUCAA - APT Workshop on Virtual Observatory
At: Sacred Heart College, Chalakudi, Kochi
(In collaboration with the IRC, CUSAT, Kochi)

July 18 - 19
Conference on Research in Astronomy: Opportunities and Challenges - III
At: University of Calicut, Kozhikode
(In collaboration with the IRC, CUSAT, Kochi)

September 11 - 12
Workshop on Basic Astronomy and Telescope Making
At: Indian Institute of Science Education and Research, Tirupati

September 13 - 14
Introductory School on Astronomy
At: Eliezer Joldan Memorial College, Leh, Ladakh

September 26 - 28
Introductory Workshop on Astrophysics and Cosmology
At: Aliah University, Newtown Campus, Kolkata
(In collaboration with the IRC, Calcutta University, Kolkata)

November 2 - 4
National Workshop on Gravitational Waves Astronomy
At: Dibrugarh University

November 15 - 18
International Conference on Oriental Astronomy
At: Indian Institute of Science Education and Research, Pune
(Partly funded by IUCAA)

November 19 - 20
Workshop on Projects in X-ray Astronomy
At: Providence College, Kozhikode

November 30 - December 2
Workshop on Introduction to Solar Astrophysics
At: Mar Athanasius College, Kothamangalam
(In collaboration with the IRC, CUSAT, Kochi)

December 12 - 14
North-East Meet of Astronomers
At: Tezpur University

December 19 - 23
Workshop on Structure Formation in Standard Cosmology
At: BITS - Pilani, Hyderabad

2017

January 12 - 14
Workshop on Statistical Analysis in Cosmology
At: Cochin University of Science and Technology, Kochi

February 2 - 4
Workshop on Stellar Astrophysics
At: Christ University, Bengaluru

March 24 - 27
Workshop on Basic Astronomy and Telescope Making
At: Centre of Excellence in Space Science - India, and the International Society for Optics and Photonics, Kolkata

Quantum Theory and Gravity

A boundary term for the gravitational action with null boundaries

Just like any other field theory, the dynamics of gravity can be obtained from an action, the Einstein-Hilbert action. On varying the action with respect to the metric, we obtain an equations of motion term and a boundary term. But the boundary term is unusual, as it contains variations both of the metric and its first derivatives, both tangential and normal to the boundary. The problem with such a structure is that it makes the variational principle ill-defined. In general, the equations of motion and the boundary conditions will turn out to be inconsistent.

There is a widely accepted prescription for resolving this issue. One adds an extra boundary term to the action, called a counter-term, such that the surface term in the variation of the new action contains only variations of the metric and does not involve the variations of the normal derivatives. Thus, we need to fix only the metric on the boundary and the variational principle becomes well-posed. The most commonly used is the Gibbons-Hawking-York (GHY) counter-term, although there are other counter-terms available in the literature. In cases where the boundary is taken to infinity, other boundary terms in addition to the Gibbons-Hawking-York term are added to make the action finite on classical solutions.

Some physical cases where we might require a counter-term for a null surface are the case of a spacetime with a black hole, where we want to consider the black hole horizon as one of the boundaries, the case of the interior of a causal diamond formed by the intersection of the future light cone from a point P and the past light cone from a point Q in the future of P, etc. Recently, **K. Parattu**, **S. Chakraborty**, B.R. Majhi and **T. Padmanabhan** have provided comprehensive discussion of these and related issues from several different perspectives and have explicitly demonstrated the necessary counter-term for null surfaces that one has to add to the Einstein-Hilbert action in order to make it well-posed.

Information retrieval from black holes

Evaporation of black holes, for many decades, has caused conceptual discomfort for the otherwise very successful quantum theory. The most basic and fundamental feature of the standard quantum theory, namely unitary evolution, is seemingly threatened if one tries extrapolating the results obtained at the semi-classical level. Insights of Bekenstein, suggested that the black holes must have an entropy proportional to the area of their event horizons, for the second law of thermodynamics to work. Hawking proved that quantum effects could lead to the evaporation of the black hole which involves (i) a radiation of positive energy, (nearly) thermal spectrum of particles which an asymptotic observer can detect and (ii)a flux of negative energy flowing into the black hole decreasing its mass. So the mass lost by the black hole appears in the form of energy of the thermal radiation. Although this effect completes the thermodynamic description of black holes, yet such a process, together with other properties of black holes, appears to violate the standard unitary quantum mechanics.

The particles in the outgoing flux, received by the asymptotic observer, remain entangled with the particles in the in-going flux. The resulting Hawking radiation is thermal, precisely because we trace over the modes which entered the horizon. By such a process, the black hole shrinks, losing the mass in the form of Hawking radiation. However, once the black hole completely evaporates by this process, there is an apparent paradox.

An initial resolution of the paradox stemmed from the idea that we might be making error in trusting the semi-classical Hawking process all the way to the complete evaporation of the black hole. In principle, when the black hole is large enough, semi-classical description should work fine. But as the black hole becomes smaller and smaller, the curvature at horizon begins to rise and at very high curvatures the quantum nature of gravity must become important, and the semi-classical approximation must break down. Therefore, quantum gravity — rather than the semi-classical physics — should govern the final moments of the black hole evaporation. It must be noted that there exist many other sources of distortions to the thermal Hawking radiation, apart form the quantum gravity induced corrections. These non-thermal corrections can, in principle, store some information. However, it can be shown that, since all such correction terms are sub-dominant in nature, none of these can help in making the theory unitary. Only corrections of $\mathcal{O}(1)$ can provide a possibility for unitary description, and we could identify no distortions of that kind. Thus, in its new scenario, the paradox seems more robust as far as restoring unitarity to the quantum evolution is concerned. When the black hole evaporates completely without leaving any remnant behind, one is justified in assuming that the entire information content of the collapsing body gets either destroyed or must be encoded in the resulting radiation. However, remnant radiation in this process is (dominantly) thermal, which is thermodynamically prohibited to contain much of the information and also incapable of making the theory unitary. Therefore, most of the information content of the matter which made the black hole in the first place is not available to the future asymptotic observers.

T. Padmanabhan, **K. Lochan** and **S. Chakraborty** have demonstrated that this version of the paradox — concerning the information content of the initial data — stems from a hybrid quantum/classical analysis of a process which is fully quantum mechanical in nature. That is, it arises from an artificial division between a quantum test field and the classical matter, which collapses to form a black hole. They also expect that the classical description to be true, at lowest order, leading to formation of an event horizon. However, the information that the collapsing material was inherently quantum mechanical in nature (e.g. a coherent state of the field which is collapsing) should not be completely ignored in studying this process. The matter which forms the black hole, if treated quantum mechanically, will populate its modes at future asymptotic non-thermally, in a manner which depends on its initial state. Thus, the no-hair theorems will be superceded at the full quantum gravity level.

Entropy of a generic null surface from its associated Virasoro algebra

It is well known that one can associate thermodynamic variables like entropy (S) and temperature (T) with null surfaces, that are perceived to be one-way membranes, by the class of observers who do not cross them. For example, observers at constant spatial coordinates located at $r > 2M$ in the Schwarzschild metric will associate a temperature $T = (1/8\pi M)$ with the black hole horizon at $r = 2M$. Similarly, an observer at constant spatial coordinates at $x > 0$ in a Rindler spacetime (with the metric $ds^2 = -g^2x^2dt^2 + d\mathbf{x}^2$) will associate a temperature $T = (g/2\pi)$ with the Rindler horizon, at $x = 0$. Both these observers will associate an entropy density (entropy per unit area) of (1/4) with the respective horizons. The freely falling observers in either spacetime will not perceive the relevant null surface as endowed with thermodynamic properties, because these observers will eventually cross these null surfaces; therefore, these null surfaces do not act as one-way membranes for these observers.

For a broad class of, rather generic, null surfaces in an arbitrary spacetime, one can introduce a set of observers who do not cross these null surfaces and perceive them as one-way membranes. It seems reasonable to assume that physics should be local and the behaviour in a local region around an event should depend only on the geometrical properties around that event. It is also widely accepted that black hole horizon has an entropy density of 1/4 per unit area. An observer close the the horizon will see that the metric is well approximated by Rindler metric and locality requires a patch of this Rindler metric to have the entropy density 1/4. It is, therefore, important to investigate whether, in such a general context, these observers will associate thermodynamic variables with such a generic null surface. Earlier work has shown that there exist several deep connections between the properties of null surfaces and gravitational dynamics which suggest that this could be true. If so, then we can obtain a unified picture of the connection between thermodynamics and null surfaces, *with all the previously known cases being reduced to just special cases of this result.*

T. Padmanabhan along with **S. Chakraborty** and **S. Bhattacharya** has shown that this is indeed the case, and has demonstrated that one can associate a very natural Virasoro algebra with a general class of null surfaces. This Virasoro algebra has a central charge which, through Cardy's formula, leads to the entropy of the null surface. The explicit calculation shows that the entropy per unit area is (1/4) which is consistent with the standard results for black hole horizons, cosmological horizons, etc.

Cosmology and Structure Formation

Correlated variables and constraints on halo formation

Traditional approaches to structure formation typically make several assumptions regarding the nature of the non-linear processes involved in the formation of gravitationally bound haloes of dark matter, and then go on to predict the resulting spatial clustering of these haloes. In a novel departure from this line of approach, Emanuele Castorina (Berkeley), **Aseem Paranjape** and Ravi K. Sheth (UPenn) have noted that one can turn the problem around, and use measurements of halo clustering to constrain the nature of the processes involved in halo formation. The key idea is that halo clustering or bias is caused by the fact that haloes form at special locations in the dark matter field. Consequently, any variable that is relevant for halo formation will be correlated with the locations of halo formation. Measurements of the values of such variables smoothed on large scales around halo locations then carry redundant information about the mechanism of halo formation. They have show,n with a variety of examples, how this redundancy can be exploited to successfully infer the nature of halo formation from measurements of halo clustering.

Excursion set peaks: The role of shear

Recent analytical work on the modelling of dark halo abundances and clustering has demonstrated the advantages of combining the traditional excursion set approach (where one counts any sufficiently overdense region not surrounded by other overdensities as a potential halo) with peaks theory (where one focuses exclusively on peaks of the initial density field). Emanuele Castorina (Berkeley), **Aseem Paranjape**, Oliver Hahn (OCA Nice) and Ravi K. Sheth (UPenn) have extended these ideas, introducing a model of excursion set peaks that incorporates the role of initial tidal effects or 'shear' in determining the gravitational collapse of dark haloes. The model in which the critical density threshold for collapse depends on the tidal influences acting on protohaloes and is well motivated from ellipsoidal collapse arguments and is also simple enough to be analytically tractable. They have shown that the predictions of this model are in very good agreement with measurements of the halo mass function and traditional scale dependent halo clustering (or halo bias) in N-body simulations across a wide range of masses and redshift. The presence of shear in the collapse threshold means that halo bias is naturally predicted to be non-local, and that proto-halo densities at fixed mass are naturally predicted to have lognormal-like distributions; both of these effects have been independently seen in simulations. The simplicity of their model (which has essentially a single free parameter) has opened the door to building efficient and accurate fitting functions of halo abundances and bias for use in precision cosmology.

Halo assembly bias from Separate Universe simulations

Assembly bias refers to the dependence of spatial clustering of collapsed dark matter halos on properties related to the assembly history of the halos, such as their half-mass formation times or their density profile concentrations. This dependence has traditionally been measured and calibrated using standard clustering estimators, such as the power spectrum or correlation function, which require running large volume, high resolution simulations. The Separate Universe technique, which maps the effects of large scale over-density to an effective FLRW spatial curvature, has recently been demonstrated by other authors to be an extremely efficient and accurate way of measuring the large scale clustering of halos as a function of halo mass, since it only requires running small volume, low resolution simulations. **Aseem Paranjape** and Nikhil Padmanabhan (Yale) have extended this technique to include the dependence on halo concentration, which has led to the most accurate calibration of linear assembly bias, as well as the first calibration of quadratic assembly bias from simulations to date. Their results have revealed the intriguing possibility of detecting assembly bias in observational samples, and mitigating its influence on cosmological analyses, by measuring both linear and quadratic bias in the same sample. They have used the IUCAA cluster Perseus for running the Separate Universe simulations.

Analytical halo model of galactic conformity

Galactic conformity is an observation that satellite galaxies in groups whose central galaxy is red are preferentially red, even when the groups are restricted to reside in dark matter haloes of the same mass. To explain this galactic phenomenon, **Paranjape**, et al. (2015) have extended the standard halo occupation distribution (HOD) framework to generate mock galaxy catalogues, which model galaxy positions, velocities, luminosities and colours. **Isha Pahwa** and **Aseem Paranjape** have further extended their work to give a fully analytical halo model of colour-dependent clustering that incorporates the effects of galactic conformity in the HOD framework. Their model (as first defined in the previous work) describes conformity through a correlation between the colour of a galaxy and the concentration of its parent halo, leading to a correlation between central and satellite galaxy colours at fixed halo mass. The strength of the correlation is set by a tunable 'group quenching efficiency' (ρ). Higher the ρ, the stronger the correlation between colour of a galaxy and the concentration of its parent halo.

Their model incorporates the effects of 1-halo conformity, i.e., difference in the red fraction of satellites corresponding to red centrals or blue centrals of similar halo mass and 2-halo conformity, i.e., a trend at fixed halo mass, in which red galaxies tend to cluster more strongly at scales $>= 1-2$ Mpc than blue galaxies. Figure 1 compares the red fraction of satellites with red centrals with that of blue centrals, as function of luminosity for $\rho = 0.9, 0.65, 0.01$ corresponding to strong, medium and no conformity respectively. Higher fraction of red satellite galaxies compared to blue satellite galaxies for red centrals (and vice-versa for blue centrals) shows the effect of 1-halo conformity for non-zero values of ρ. Figure 2 shows the effect of 1-halo and 2-halo conformity on the correlation functions of red and blue galaxies for different values of ρ. This figure depicts the relative difference between the red and blue galaxies clustering, and the strength of this difference is controlled by ρ. They also validate their analytical results using clustering measurements in mock galaxy catalogues of Paranjape, et al. 2015 and find that their model is accurate at the 10-20 percent level for a wide range of luminosities and length scales.

An order statistics approach to the halo model for galaxies

Niladri Paul and **Aseem Paranjape** and Ravi Sheth, have studied the implications of assuming that luminosities of galaxies in a group are randomly drawn from an underlying universal galaxy luminosity function. Using this assumption within the framework of halo model, they found that a number of observable properties of the galaxies, e.g., monotonic relation of the mean central luminosity with halo mass, the log-normal distribution of the central luminosities, and the tight relation between central and satellite mass scales can be explained. But this simple model based on order statistics was incapable of explaining the luminosity dependence of the clustering of the galaxies. To explain that property, they took into account the halo mass dependence of the universal luminosity function. This order statistics model based on conditional luminosity function (CLF) is sufficient

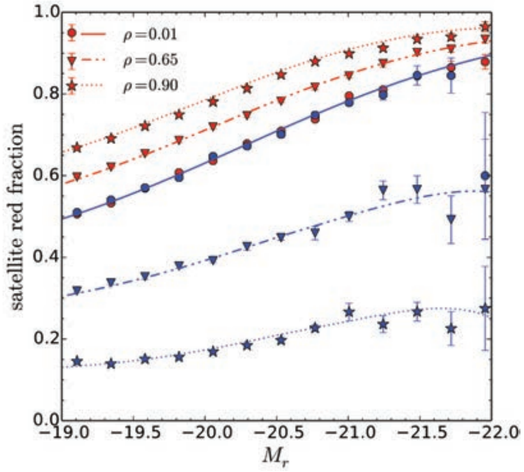


Figure 1: Red fraction of satellites with red centrals (upper, red) and blue centrals (lower, blue) as a function of luminosity: Points with errors show measurements in the mock catalogues of Paranjape, et al. 2014 and smooth curves show the corresponding results of this analytical model. The measurements in the mocks were averaged over 10 independent realisations, with the error showing the standard deviation around the mean. Circles/solid lines show results for 'no conformity' with $\rho = 0.01$, triangles/dot-dashed lines are for 'medium' conformity with $\rho = 0.65$, while stars/dotted lines show results for 'strong' conformity with $\rho = 0.9$.

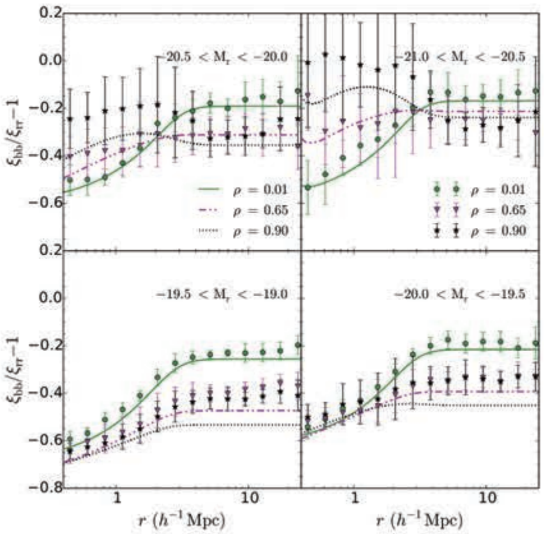
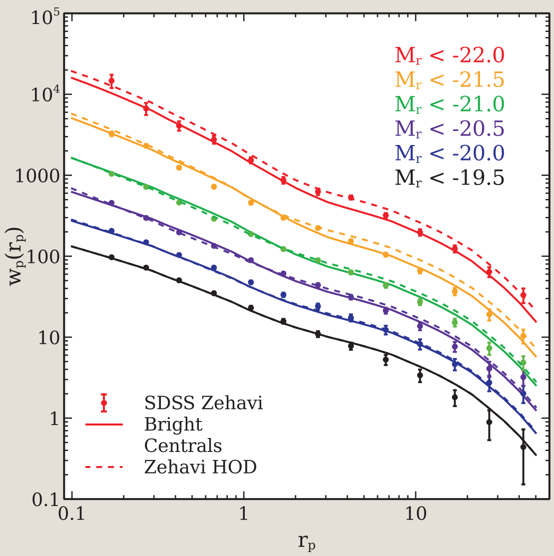


Figure 2: The effect of introducing 1-halo conformity and 2-halo conformity in the correlation function: This figure compares the excess of blue galaxy correlation function over that of the red for $\rho = 0.01, 0.65$ and 0.9 represented by the solid green, dot-dashed magenta and dotted black lines respectively. The different symbols are the mean of the corresponding results from 10 independent mocks with standard deviation as the error bars on them. The different panels correspond to the different luminosity bins as indicated.



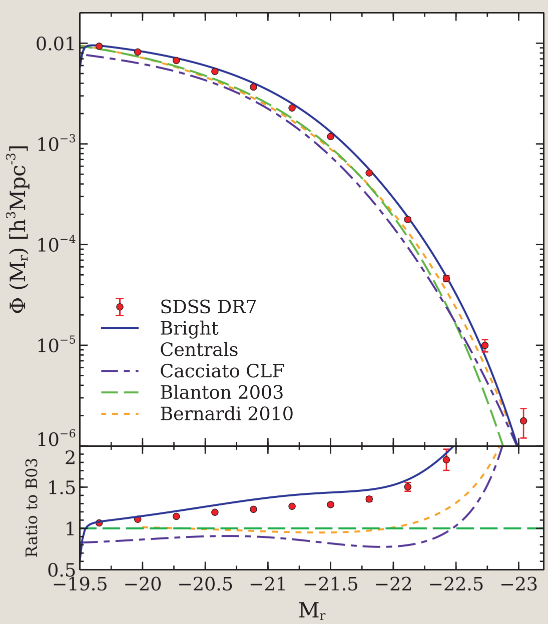


Figure 3: The upper panel of this figure shows the projected correlation functions of galaxies at different magnitude thresholds. The solid points with error bars are measurement from SDSS survey, the dotted curves are the computed correlation function using standard Halo model parameters of Zehavi et al. (2011) and the solid curves are those computed using our OS model where the centrals are brightened. The bottom panel of the figure shows the galaxy luminosity function as computed using our model with bright centrals (solid curve) and the one measured from SDSS (red solid points).

enough to explain the two point correlation function as observed from the SDSS data and other observable properties as mentioned above. But the luminosity of the central galaxies are predicted to be systematically lower than that is observed in this model. To account for this, the central galaxies were brightened in a statistical way. **Paul** et al. (2017) found that it was sufficient to brighten only those galaxies living inside haloes of a typical mass scale. This new model based on brightened centrals could successfully predict the luminosity distribution in the central galaxies along with the other observables as shown in Fiure. 4 and 3. This order statistics framework provides a useful language in which one can compare the halo model for galaxies with more physically motivated galaxy formation models.

Dark matter and dark energy from α-attractors

Dark matter (DM) and dark energy (DE) are two of the most enigmatic observables in current cosmology. While DM is assumed to be pressureless, DE is believed to have large negative pressure which accelerates the present universe. It is accepted that DM must cluster, in order to account for the missing-mass problem associated with individual galaxies and with galaxy clusters. Furthermore, there are strong reasons to believe that DM must have already been in place by redshifts of $z \gtrsim 10^4$. This is indicated by primordial fluctuations in the cosmic microwave background (CMB), whose small amplitude ($\Delta T/T \sim 10^{-5}$) is suggestive of an equally small amplitude of primordial density fluctuations at $z \gtrsim 10^3$. Such small fluctuations would have had difficulty in growing to the much larger values today, $\delta\rho/\rho > \mathcal{O}(1)$, in a universe consisting solely of baryons.

The origin of DE could, on the other hand, be much more recent, since there is observational evidence to suggest that the universe commenced accelerating at $z \lesssim$ few.

Theoretical models of DM usually subscribe to the view that it is made up of hitherto undetected elementary particles called WIMPs (weakly interacting massive particles). However, despite several

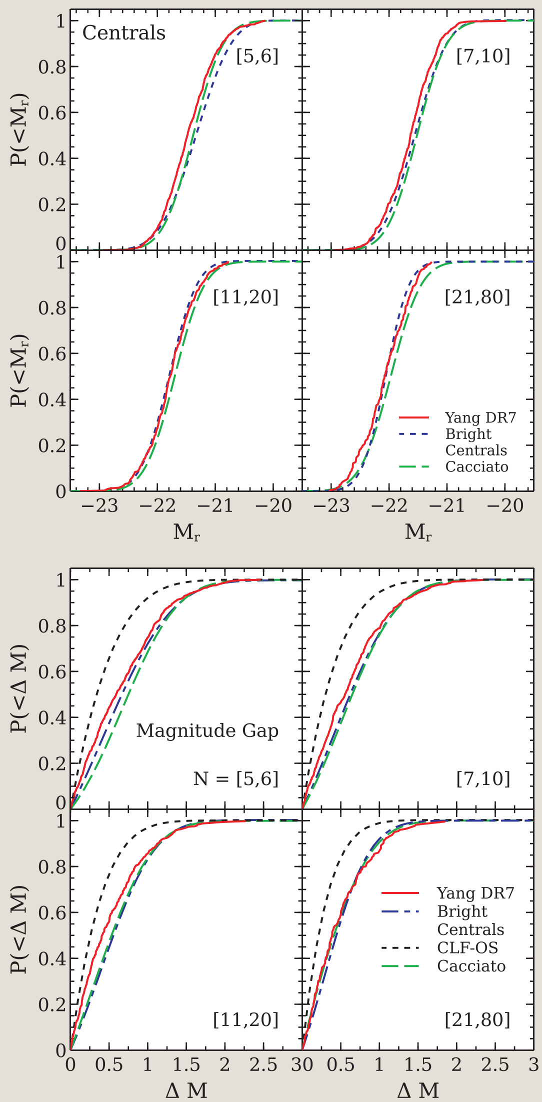


Figure 4: The upper panel of this figure shows the cumulative luminosity distribution of the centrals galaxies in a group of fixed richness and the bottom panel shows the magnitude gap in those groups. Again we see that our OS model with centrals brightened (blue dashed curve) matches quite well with the data from Yang 2007 group catalogue (the solid red curve).

decades of systematic searches by elaborate experiments, a firm consensus on the existence of WIMPs has eluded researchers. Our understanding of DE faces an even greater dilemma since its basic properties, such as its pressure and density, have only been indirectly deduced via cosmological observations of the expansion history or the luminosity distance.

Swagat Mishra, Varun Sahni and Yuri Shtanov move past the dominant paradigm of particle-like WIMP dark matter and examine the alternative possibility that DM could have the structure of a scalar field. Ever since the advent of Inflation, scalar field models have played an increasingly prominent role in our understanding of the very early universe. Scalar-field models have also been advocated to describe dark energy. Recently, Kallosh and Linde have discussed a new class of scalar field models, called α-attractors, which have an attractive feature of describing an entire family of inflationary models within a common theoretical setting. α-attractors also have an important theoretical underpinning within the framework of supergravity. **Misra**, **Sahni** and Shtanov have shown how the α-attractors may have an even wider appeal, since they can describe dark matter, and perhaps even dark energy.

An important feature of the entire α-attractor family is that all its potentials have the asymptotic form $V(\varphi) \simeq V_0 \left(\frac{\lambda\varphi}{m_p}\right)^{2n}$ for $\lambda\varphi \ll m_p$. It is well known that a scalar field oscillating about the minimum of such a potential will have the time-averaged equation of state (EOS)

$$\langle w \rangle = \left\langle \frac{p}{\rho} \right\rangle = \frac{n-1}{n+1} \ .$$

Consequently, for $n = 1$, the scalar field will be pressureless and behave just like DM. For $n < 1/2$, on the other hand, the EOS $\langle w \rangle < -1/3$ violates the strong energy condition. Such a field could, therefore, play the role of DE by causing the universe to accelerate.

However the simplest DM potential, $V = \frac{1}{2}m^2\varphi^2$, runs into considerable fine tuning problems as shown in Figure 5. The tendency of ρ_φ to behave like a cosmological constant deep within the radia-

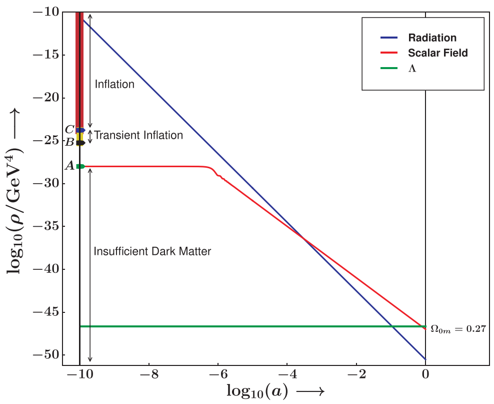


Figure 5: This figure describes the fine tuning associated with the initial scalar field density associated with the dark matter potential $V = \frac{1}{2}m^2\varphi^2$. One finds that the scalar-field energy density remains frozen to its initial value all the way until $z \sim 10^6$. During this period the scalar field behaves like a cosmological constant. Therefore, if its density is large it can make the universe accelerate (inflate). The initial scalar-field value which results in $\Omega_{0m} \simeq 0.27$ is shown by the green point A. The brown colour band (commencing upwards from C) indicates the range of initial energy-density values, which drive the universe into an inflating (accelerating) phase that lasts until the present epoch. The narrow green band with $\rho_i \in (\rho_B, \rho_C)$ corresponds to a universe which experiences transient acceleration. Initial values of $\rho_i < \rho_A$ result in an insufficient amount of dark matter at the present epoch ($\Omega_{0m} < 0.27$), whereas $\rho_A < \rho_i < \rho_B$ lead to too much dark matter. One, therefore, finds that, for a given value of m (in this case, 10^{-22} eV), only a very narrow range of initial values of φ near point A can lead to a current value of Ω_{0m} within the observational constraints. Namely, $0.057\ m_p \le \varphi_i \le 0.062\ m_p$ results in $\Omega_{0m} = 0.27 \pm 0.03$. This emphasises the enormous fine tuning associated with this model of dark matter.

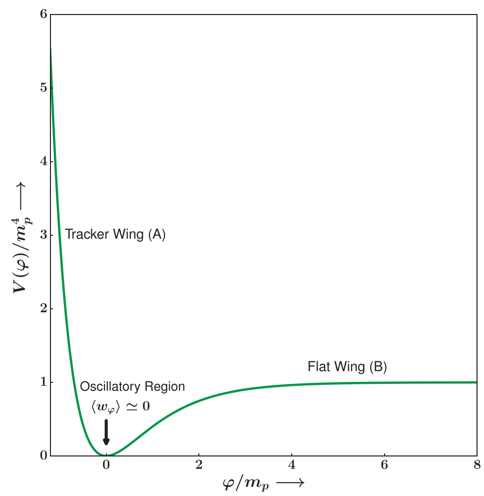


Figure 6: This figure schematically illustrates the Starobinsky potential. The main features of this potential are: The exponential tracker wing for $\lambda|\varphi| \gg m_p$ ($\varphi < 0$), the flat wing for $\lambda\varphi \gg m_p$, and the oscillatory region for which $\lambda|\varphi| \ll m_p$, so that $V \simeq \frac{1}{2}m^2\varphi^2$.

tive regime enormously influences the kind of initial conditions that need to be imposed on the scalar field in order that the model universe resemble ours (i.e., with $\Omega_{\rm de} \simeq \frac{2}{3}$, $\Omega_{\rm dm} \simeq \frac{1}{3}$, $\Omega_{\rm b} \simeq 0.04$, and $\rho_r \simeq 10^{-5}$).

This fine tuning is easily alleviated if DM is based on the Starobinsky potential:

$$V(\varphi) = V_0\left(1 - e^{-\lambda\frac{\varphi}{m_p}}\right)^2 ,$$

which is a member of the α-attractor family.

This potential exhibits three asymptotic regions (see Figure 6):

It is well known that, in the context of Starobinsky inflation, only the flat wing of the potential sustains inflation since the tracker wing is much too steep to cause accelerated expansion. For DM, on the other hand, it is the steep wing with $V \sim e^{2\lambda\frac{|\varphi|}{m_p}}$ that is more useful.

The results of **Swagat Mishra**, **Varun Sahni** and Shtanov summarized in Figure 7, demonstrate that initial energy-density values covering a range of more than 9 orders of magnitude at $z = 10^{10}$ converge onto the attractor scaling solution which gives rise to $\Omega_{0m} \simeq 0.27$ at present. This range substantially increases if we place our initial conditions at earlier times. For instance, if one sets $\{\varphi, \dot{\varphi}\}$ at the GUT scale of 10^{14} GeV ($z \sim 10^{26}$), then the range of initial density values that converge to $\Omega_{0m} \simeq 0.27$ is an astonishing 82 orders of magnitude! The tracker branch of the Starobinsky potential, therefore, allows a much greater freedom in the choice of initial conditions than the $m^2\varphi^2$ potential.

An important property of scalar field dark matter (SFDM), explored by **Swagat Mishra**, **Varun Sahni** and Shtanov is that it has a Jeans length below which gravitational clustering is suppressed. For a scalar field oscillating near the minimum of an $m^2\varphi^2$ potential, the Jeans length is

$$\lambda_J = \pi^{3/4}(G\rho)^{-1/4}m^{-1/2} \ . \tag{1}$$

An oscillating scalar field with a mass of 10^{-22} eV would, therefore, have Jeans length of a few kiloparsec. Such a large Jeans length would inhibit gravitational clustering on small scales thereby helping to resolve the cusp–core dilemma faced by standard cold dark matter (CDM) in the context of dwarf spheroidal galaxies. A macroscopically large Jeans length might also ameliorate the substructure problem in CDM. It is of interest to note that oscillations in the gravitational potential associated with SFDM can induce oscillations in the photon arrival time from milli-second pulsars. This effect may be detectable by future experiments such as the square kilometer array (SKA), pulsar timing array, and laser interferometric gravitational wave detectors. Finally, it is important to note that ultra-light scalar fields (pseudo Nambu–Goldstone bosons) arise naturally in string theory via the breaking of exact shift symmetry.

The following generalization of the Starobinsky potential

$$V(\varphi) = V_0\left(1 - e^{-\lambda\frac{\varphi}{m_p}}\right)^{2n}, \qquad n < \frac{1}{2},$$

can source dark energy; (see Figure 8). For small values of the scalar field, the potential has the form $V(\varphi) \simeq V_0\left|\frac{\varphi}{m_p}\right|^{2n}$, which results in a negative equation of state: $\langle w\rangle = \frac{n-1}{n+1} < -1/3$.

Other α-attractor potentials also have interesting properties, as comprehensively shown by **Swagat Mishra**, **Varun Sahni** and Shtanov in arXiv:1703.03295.

Constraining the cosmology of the phantom brane

The unexpected faintness of distant supernova Type Ia, as observed concurrently by the Supernova Cosmology Project (SCP) and the High Redshift Search Team (HZT) in the late 1990s, has led to the postulation of one of the most mystifying cosmological phenomena-the accelerated expansion of the Universe. One way to explain this observational result is to theorize the existence of a new form of energy, with negative pressure, often called 'dark energy'. A different approach to the problem of cosmological acceleration consists of introducing new physics in the gravitational sector. Einsteinian gravity is very well tested within the solar system, but may be modified on larger scales. Different models of modified gravity have been suggested to explain the accelerated expansion of the universe, including $f(R)$ models, Galileons, etc. An important sub-class of modified gravity is the braneworld scenario. According to this scenario, our observable universe is situated in a four-dimensional brane embedded in a fifth dimension, the 'bulk', and the accelerated expansion of the universe is a consequence of this extra-dimensional modification of gravity.

Ujjaini Alam, **Satadru Bag** and **Varun Sahni** have tested a popular braneworld model, called the 'phantom brane', against observations. The phantom brane has several interesting properties, which distinguish it from conventional models of dark energy including ΛCDM. The presence of the fifth dimension introduces a new length scale into the universe. This length scale is defined in terms of the ratio between the four and five dimensional Planck masses, m and M respectively, namely $\ell = 2m^2/M^3$. On short length scales $r \ll \ell$ (early times) one recovers general relativity, whereas on large length scales $r \gg \ell$ (late times) brane-specific

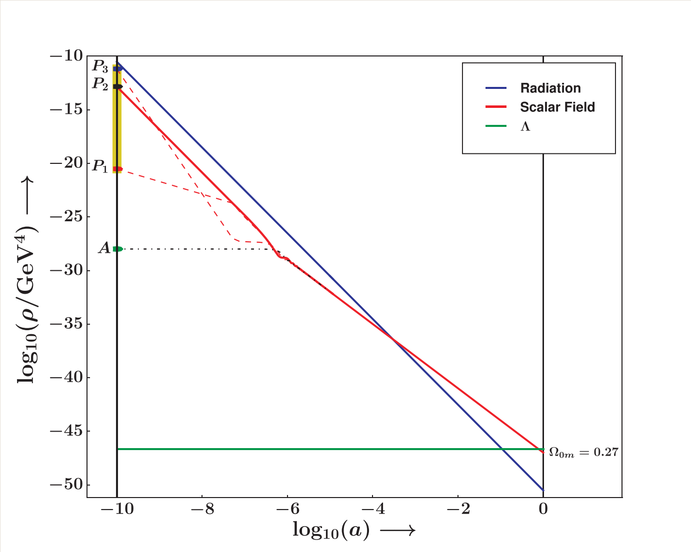


Figure 7: This figure describes the evolution of the scalar-field density from $z \simeq 10^{10}$ until $z = 0$ under the influence of the Starobinsky potential. The scalar field commences its descent from the steep left wing (‘A’ in figure 6) of the potential. The band from P_1 to P_3 represents the range in the initial (scalar-field) density that leads to a reasonable value for the dark-matter density at the present epoch, namely $\Omega_{0m} \simeq 0.27$. Point P_2 marks the initial energy density corresponding to the attractor solution (solid red line) to which all trajectories starting in the P_1–P_3 band converge (prior to the commencement of oscillations in φ). This behaviour is in sharp contrast to that of dark matter sourced by the $V(\varphi) = \frac{1}{2}m^2\varphi^2$ potential, for which only a very narrow finely tuned range of values of the initial energy density (around point A) lead to $\Omega_{0m} \simeq 0.27$.

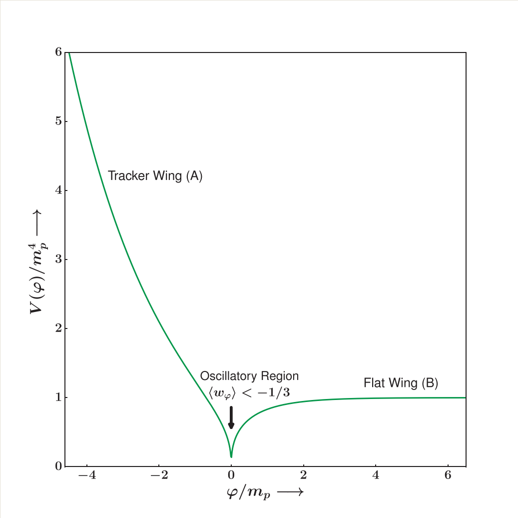


Figure 8: This figure schematically illustrates the modified Starobinsky potential. The main features of this potential are: (A) the exponential tracker wing for $\lambda|\varphi| \gg m_p$ ($\varphi < 0$), (B) the flat wing for $\lambda\varphi \gg m_p$, and the oscillatory region for which $\lambda|\varphi| \ll m_p$, so that $V(\varphi) \simeq V_0\,|\varphi/m_p|^{2n}$. Since $n < 1/2$ oscillations of the scalar field give rise to an average equation of state, which is *negative* and can cause the universe to accelerate at late times.

effects begin to play an important role, leading to the acceleration of the universe at late times.

There are two important features of the phantom brane: (i) Its equation of state is *phantom-like* with $w < -1$. (ii) The effective cosmological constant on the brane can be *screened*. The latter can be demonstrated by writing the expansion history on the brane in the suggestive form:

$$h^2(z) = \Omega_{0m}(1+z)^3 + \Omega_\Lambda - f(z).$$

The value of the screening term $f(z)$ *increases* with redshift. This allows the expansion rate to *fall below* the ΛCDM value of $h^2(z) = \Omega_{0m}(1+z)^3 + \Omega_\Lambda$ at high redshifts. Because of this effect the phantom brane may provide a better fit to high-z baryon acoustic oscillations data than ΛCDM. A key feature of such a 'screened dark energy' model is that if $f(z)$ increases monotonically with redshift, then eventually the cosmological constant, Ω_Λ, will be cancelled by $f(z)$, so that $h^2(z_p) = \Omega_{0m}(1+z_p)^3$. At this redshift, z_p, the effective equation of state of dark energy will develop a pole at which $w_{\rm eff}(z_p) \rightarrow \infty$. In the context of the phantom brane, the pole in $w_{\rm eff}(z)$ is shown in figure 9. The presence of a pole in the EOS of dark energy, therefore, emerges as a *smoking gun* test for this class of Braneworld models.

Ujjaini Alam, **Satadru Bag** and **Varun Sahni** have tested the braneworld scenario using observations of Type Ia supernovae (SNIa) and BAO. Their results show that these data sets allow $\Omega_\ell \lesssim 0.3$ at 1σ. However, when the compressed CMB data is added, the constraints become much stronger: The Ω_ℓ parameter being constrained at 1σ to $\Omega_\ell \lesssim 0.1$ (see Figure 10). The best fit value of the brane parameters for the full data set SNIa+BAO+CMB is $w_0 = -1.06 \pm 0.03$ and $\Omega_\ell = 0.047^{+0.031}_{-0.047}$. Ujjaini Alam, **Bag** and **Sahni**, therefore, conclude that phantom braneworld models are well constrained by current distance measures but by no means ruled out. It is indeed possible to construct braneworld models compatible with the current observations in which brane-specific effects can cause the acceleration of the cosmological expansion, thus, offering a complementary approach to the dark energy problem.

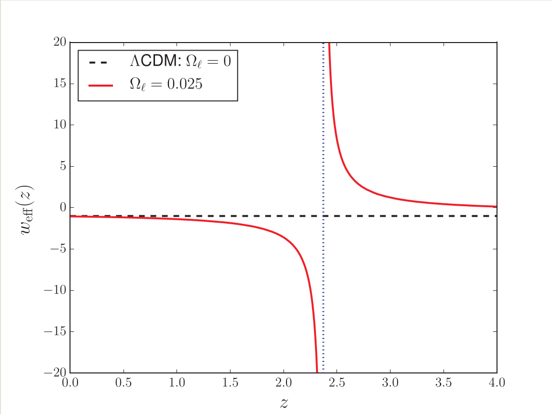


Figure 9: The effective equation of state of dark energy ($w_{\rm eff}$) is shown as a function of redshift for $\Omega_\ell = 0.025$, assuming $\Omega_{0m} = 0.28$. A pole occurs at $z_p \approx 2.372$. At large redshift, $w_{\rm eff}(z) \rightarrow -1/2$ for any non zero value of Ω_ℓ and Ω_{0m}. For $\Omega_\ell = 0$, i.e. in the ΛCDM limit, the pole disappears as shown by the dashed line. (Note that $\Omega_\ell = 1/\ell^2 H_0^2$).

Astrobiology

ISRO has under consideration a proposal submitted by **Jayant Narlikar** for the third balloon experiment to collect and examine micro-organisms in the stratosphere. The proposed examination is of ratios of 12_C and its isotopes 13_C, 14_C, etc. These will be compared to similar ratios from terrestrial micro-organisms, and if found different, may provide an unequivocal demonstration of their extra-galactic origin.

Search for very old stars

Further studies of stellar inputs from missions like Gaia tell us if there are some stellar samples which have stars as old as 20 Gyr. Such stars, if found, will provide evidence for the universe being very old, thus constraining cosmology farther. This study has been done by **Jayant Narlikar**.

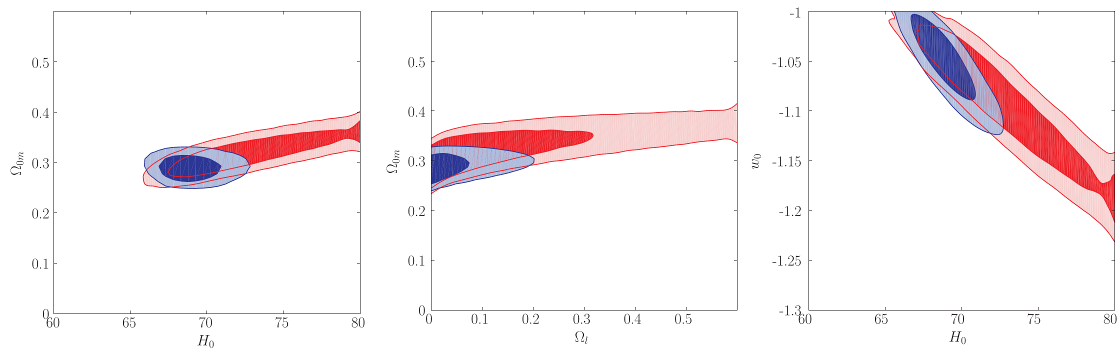


Figure 10: $1, 2\sigma$ confidence levels in the $\Omega_{0m} - H_0$ (left panel), $\Omega_{0m} - \Omega_\ell$ (middle panel), $w_0 - H_0$ (right panel) parameter space for the phantom brane using SNe Union2.1 + BAO high and low z data + compressed CMB data. The red contours represent results for just the SNe + BAO data, while the blue contours represent results for all three datasets. $\Omega_\ell = 0$ represents ΛCDM.

Gravitational Waves

The ambiguity χ^2 discriminator

The noise in an interferometric detector is neither Gaussian nor stationary and is contaminated by noise which can come from the detector itself or the environment. Matched filtering, the commonly employed technique for extracting known signals from noise is by itself not sufficient to distinguish the signal from the noise. Often these noise features or glitches have large power and even if their match may be small with the template bank, they produce detectable triggers. Additional vetoing techniques are required to discriminate the noise versus the signal. The test designed by Bruce Allen (traditional) does just this. It splits the broadband data into several smaller bands and checks for consistency between the power expected from the signal in the sub-band with the observed power in that sub-band.

But this is not the only type of discriminator that can be constructed. Here, **Sanjeev V. Dhurandhar** et al. propose another discriminator based on the ambiguity function - called the ambiguity discriminator, which uses information about how the templates in the neighbourhood of the trigger template respond to the signal as opposed to noise glitches. Moreover, it has very little overheads, because it uses essentially precomputed results - the filtered output from a bank of templates. The obvious advantage is that it is inexpensive because the extra computations are very less as compared to the computational cost of searching through the data with a bank of templates. This test is proposed as an alternative test to the traditional one - it will complement the traditional and thus help in discriminating against noise. From a general point of view, it is shown that a wide variety of such discriminators are possible and thus, it may be possible to carry out various types of optimisations in arriving at a discriminator which performs best.

Newtonian noise subtraction using optimized sensor arrays

Newtonian noise poses a fundamental limit to the low frequency sensitivity of terrestrial gravitational wave detectors. Seismic vibration induces perturbations in density, leading to local variation in the Newtonian gravitational field. These fluctuations will be the dominant noise source in the third generation GW detectors, especially around 10 - 30 Hz, and may even affect the Advanced LIGO sensitivity. As this couples directly to the test mass, it cannot be removed via passive vibration isolation and requires the Wiener filtering to achieve mitigation. **Nikhil Mukund** et al., have developed the first realistic scheme to subtract gravity gradient a.k.a Newtonian noise using measured seismic fields at the LIGO observatory. This noise if not removed could potentially limit the sensitivity of the detector in the low frequency band (10 - 30 Hz). Part of the challenge was to find the optimal seismic sensor array solutions, which needed to be deployed to subtract the noise via Wiener filtering. It was achieved through the careful construction of a parallelized simulated annealing optimizer, which could yield global minima solutions in reasonable time scales (see Figure 11). The developed scheme has the potential to be used for three dimensional sensor geometry that would be required for future underground GW projects like Einstein telescope.

Machine learning for Advanced LIGO detector characterization

LIGO strain channel data often shows presence of non-astrophysical transient events which can have a wide variety of origin. Often these have very similar morphology to the actual gravitational wave burst signals that we are looking for in the data and thus, leads to many false triggers in various data analysis pipelines. Thus, it becomes crucial to develop robust techniques which can look into the data and can distinguish between these transients and veto them with least human effort. **Nikhil Mukund** et al., have developed machine learning based technique which combines features of both supervised and unsupervised classifier to accurately distinguish between various transients seen in the data. **Nikhil Mukund** et al., have demonstrated the resourcefulness of the developed hybrid classifier by applying it on Advanced LIGO first observation run data to identify and classify major transient events. They have showed its capabilities by classifying real triggers with signal to noise ratio as low as eight. Many of these are currently limiting the search for astrophysical signals particularly Supernova and Cosmic Cusp signals. They also identified time coincidence between a particular class of triggers and the triggers observed in LIGO auxiliary channels which points to its origin and coupling. This information could be used to define data quality veto flags, which will lower the overall noise background and improve false alarm rate. Comparison with traditional classifier was done to emphasize the accuracy and lower misclassification rate of our scheme (see Figure 12). Efficient wavelet based feature extraction coupled to difference boosting neural network along with GPU capabilities makes our classifier ideal for real time tracking and mitigation of non-astrophysical transients.

Limiting the effects of earthquakes on gravitational-wave interferometers.

The LIGO seismic noise isolation systems are designed to provide maximum noise suppression at frequencies above one Hertz so as to increase sensitivity to astrophysical events. This makes the instrument vulnerable at earthquake band (30 mHz to 100 mHz) and microseismic band (0.1 Hz to 0.3 Hz). Trying to acquire lock (reach low noise state ideal for observation) during elevated levels of ground motion can be detrimental, as the seismic isolation systems can sense and feedback large motion to the various suspension stages that hold the test mass mirrors. **Nikhil Mukund** et al., have developed a real time earthquake warning system that collects related data and estimate the ground motion expected at various gravitational wave observatories around the world (LIGO, VIRGO, KAGRA, GEO). They have constructed an empirical equation that predicts ground motion from Rayleigh surface waves and constrained its parameter coefficients by running a global optimization making use of past data. In addition, they have made use of machine learning to develop a predictor that provides the lockloss probability associated with any reported significant earthquake.

Transient classification in LIGO data using Difference Boosting Neural Network

Detection of short duration gravitational waves (GW) in LIGO data requires reliable identification and removal of noise transients produced by a variety of non-astrophysical sources. Noise transients present in the data reduces the reliability of a GW detection by increasing its false alarm probability.

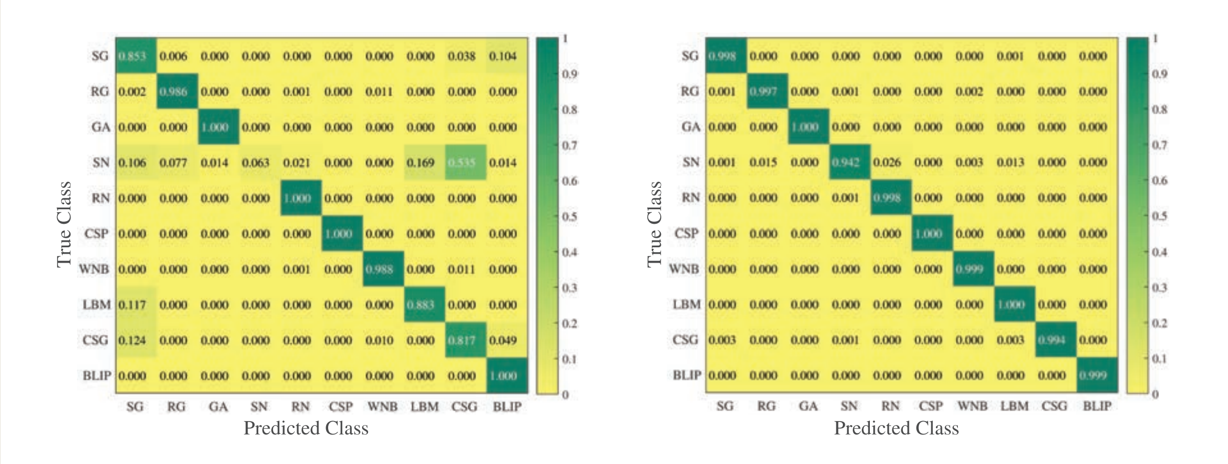


Figure 11: Confusion matrix for simulated transients signals: Results from traditional SVM (left) and DBNN (right) classifiers. Closer a diagonal element to unity, better is the classification for the corresponding type. Accuracy of our method is thus evident.

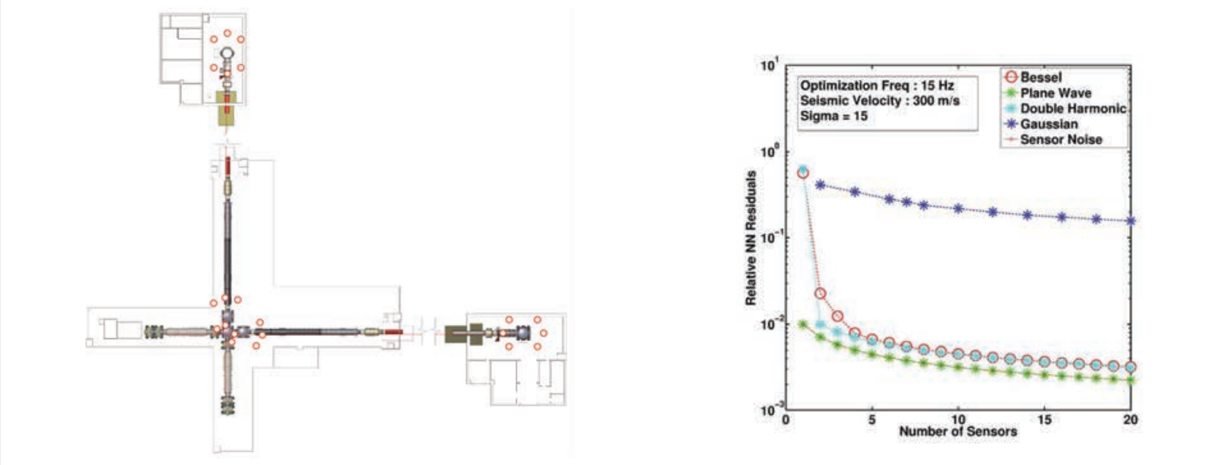


Figure 12: Left panel shows the optimal seismometer array solution for Newtonian noise cancellation from Rayleigh Surface Waves. Noise subtraction possible using optimized arrays for various cases of seismic fields, and is shown in the right panel

Nikhil Mukund, Sheelu Abraham, Shivaraj Kandhasamy, **Sanjit Mitra** and Ninan Sajeeth Philip have developed a hybrid method for classification of short duration transients seen in gravitational wave data using both supervised and unsupervised machine learning techniques. To train the classifiers, the authors have used the relative wavelet energy and the corresponding entropy obtained by applying one-dimensional wavelet decomposition on the data. The prediction accuracy of the trained classifier on nine simulated classes of gravitational wave transients and also LIGOs sixth science run hardware injections have been reported. Targeted searches for a couple of known classes of non-astrophysical signals in the first observational run of Advanced LIGO data are also presented. The ability to accurately identify transient classes using minimal training samples makes the proposed method a useful tool for LIGO detector characterization as well as searches for short duration gravitational wave signals.

Observational Cosmology and Extragalactic Astronomy

Distribution of cold gas around $z < 0.4$ galaxies

The H I gas in a galaxy's extended disc plays an indispensable role in the galaxy formation and evolution by acting as the intermediary phase between the accreting ionized gas from the intergalactic medium (IGM) and the molecular gas phase in the stellar disc that gets converted to stars. Being more extended than the stellar disc (typically by more than a factor of 2), the H I disc is also the component that gets affected the most by tidal interactions and merger events. Therefore, the H I cross-section of galaxies and its evolution with redshift is expected to have an imprint on galaxy formation in the hierarchical structure formation models.

In the local Universe ($z \lesssim 0.2$), high spatial resolution H I 21-cm emission studies have been used to map the distribution and kinematics of the atomic gas around galaxies. However, sensitivities of present day radio telescopes make it difficult to directly map H I 21-cm emission from $z \gtrsim 0.2$ galaxies. Alternatively, absorption lines seen in the spectra of background quasars whose sightline happen to pass through the discs or halos of foreground galaxies (such fortuitous associations are refer to as quasar-galaxy-pairs or QGPs from hereon), allow one to probe the physical, chemical and ionization state of gas in different environments such as the stellar discs, extended HI discs, high velocity clouds, outflows, accreting streams and tidal structures. **Rajeshwari Dutta**, **R. Srianand**, **Neeraj Gupta** and their collaborators (Patrick Petitjean, Pasquier Noterdaeme, Emmanuel Momjian and Hadi Rahmani) have conducted a large survey of 21-cm absorption towards low-z QGPs using GMRT, VLA and WSRT. This is the largest survey of this kind reported till date.

Their primary sample of 40 QGPs spans a range of impact parameters (5−34 kpc) and galaxy types (log $M_* \sim$7.8−11.0 $M_\odot$, log $L_B \sim$8.5−10.6 $L_\odot$, $g - r \sim$ 0.1−1.6). The H I 21-cm spectral line measurements from their survey have increased the number of existing sensitive H I 21-cm optical depth measurements at low-z by a factor ∼3. They have detected H I 21-cm absorption from seven QGPs in their primary sample (see Figure 13 for example). The H I 21-cm detections from their survey have increased the existing number of detections from $z <$ 0.4 QGPs by almost a factor of two. Combining their primary sample with measurements from the literature having similar optical depth sensitivity, they have quantified the H I 21-cm optical depth and covering factor of H I 21-cm absorbers as a function of spatial location around low-z galaxies. The main results from the survey are listed below:

- The H I 21-cm optical depth and impact parameter (b) are weakly anti-correlated. Performing survival analysis by including the upper limits as censored data points, **Dutta** et al., obtain, $r_k = -0.20$, $P(r_k) = 0.01$, $S(r_k) = 2.42\sigma$. Similar anti-correlation is also present between $\int \tau dv$ and the radial distance along the galaxy's major axis, as well the impact parameter and the radial distance scaled with the effective H I radius of the galaxies.

- It is found that the covering factor of H I 21-cm absorbers is $0.24^{+0.12}_{-0.08}$ at $b \leq 15$ kpc and decreases to $0.06^{+0.09}_{-0.04}$ at $b = 15{-}35$ kpc when a limiting optical depth of 0.3 km s^{-1}is used. The average covering factor within $b = 30$ kpc is $0.16^{+0.07}_{-0.05}$.

- The H I optical depth shows weak anti-correlation ($r_k = -0.17$, $P(r_k) = 0.07$, $S(r_k)$ = 1.79σ) with the azimuthal orientation of the radio sightline with respect to the galaxy's major axis. There is similar weak correlation between $\int \tau dv$ and $sin(i)cos(\phi)$, i.e., $\int \tau dv$ shows mild increase with increasing galaxy inclination and decreasing orientation. However, these could be driven by the stronger and more significant anti-correlation of $\int \tau dv$ with b, since these parameters are correlated with b in the sample.

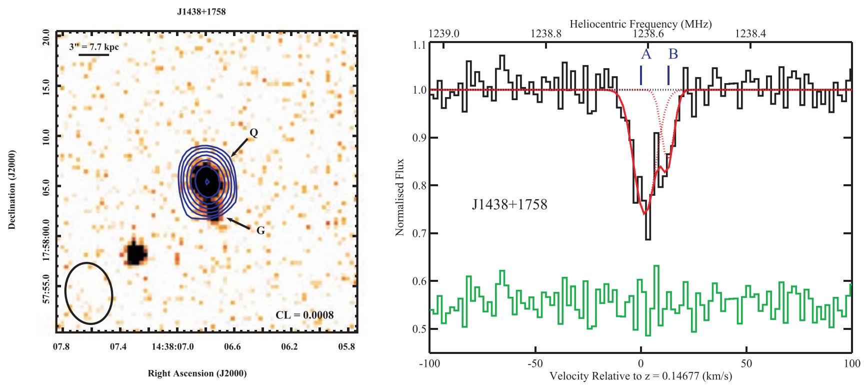


Figure 13: *Left:* SDSS r-band images overlaid with the 1.4 GHz continuum contours of the QGPs J1438+1758. The quasar is marked by 'Q' and the galaxy is marked by 'G'. The restoring beam of the continuum map is shown at the bottom left corner. The spatial scale is indicated at the top left corner. The contour levels are plotted as CL $\times$ (-1,1,2,4,8,...) Jy beam^{-1}, where CL is given in the bottom right of each image. The rms in the images (a) and (b) are 0.2 and 0.5 mJy beam^{-1}, respectively. *Right:* H I 21-cm absorption spectra towards J1438+1758. Individual Gaussian components and the resultant fits to the absorption profile are plotted as dotted and continuous lines, respectively. Residuals, shifted by an arbitrary offset for clarity, are also shown. Locations of the peak optical depth of the individual components are marked by vertical ticks.

- They have found that the covering factor is $0.20^{+0.14}_{-0.09}$ near the galaxy major axis ($\phi < 45°$) and $0.04^{+0.09}_{-0.03}$ near the minor axis ($\phi \geq 45°$), and this declining trend of covering factor with increasing ϕ is also seen at $b < 15$ kpc. This tentative indication shows that most of the H I 21-cm absorbers could be co-planar with that of the H I disk and is supported by the fact that the only two H I 21-cm detections at $b \geq 15$ kpc in the Combined sample arise from face-on galaxies. Further, the covering factor is maximum ($0.31^{+0.24}_{-0.15}$) for sightlines that pass near the major axis of edge-on galaxies ($i \geq 58°$). If this is true even for high-z galaxies, then it will have important implications for the detection rate of H I 21-cm absorption towards Mg II absorbers, which are found to be typically tracing the halo gas and not the extended H I disks. However, high-z galaxies are not expected to have such well-formed H I disks, but to be more irregular. Hence, the dependence of H I absorption on galaxy orientation needs to be probed over a larger redshift range.

- No significant dependence of $\int \tau dv$ and covering factor on galaxy luminosity, stellar mass, colour and surface star formation rate density is found from the present data. However, their results suggest that the H I 21-cm absorbing gas cross-section may be larger for the brighter galaxies. A correlation between $\int \tau dv$ and covering factor and properties associated with star formation in galaxies are expected from the models of ISM. Hence, it appears that most of the sightlines are outside the stellar disks of galaxies and probably tracing the outer quiescent regions that are not affected by the ongoing star formation activities.

- No correlation is found between H I 21-cm optical depth and W_r(Ca II) or W_r(Na I). They also find that W_r(Ca II) and the ratio W_r(Na I)/W_r(Ca II) suggest that most of the H I 21-cm, absorbers observed around low-z galaxies are not tracing the dusty star-forming disks.

- From the data available in the literature, it is found that the covering factor of H I 21-cm absorption from host galaxies of $z < 1$ DLAs ($0.62^{+0.30}_{-0.21}$%) is a factor of $\sim$4 times higher compared to that from the galaxy-selected QGPs. There is also no correlation between $\int \tau dv$ and b for DLAs. This result is analogous to the finding that the covering factor of Mg II gaseous haloes around galaxies is close to 1 when one searches for galaxies around Mg II absorbers, and is lower when one searches for Mg II absorption along sightlines close to known galaxies. Broadly, they can conclude that the H I distribution around galaxies that can contribute to the DLA population is patchy (i.e ., with a covering factor of about 30%) and about 60% of the DLAs have cold gas that can produce detectable H I 21-cm absorption. Such a picture will be consistent with the observed covering factors of DLAs and H I 21-cm absorbers around galaxies and fraction of DLAs producing H I 21-cm absorption.

- The authors have estimated the number of 21-cm absorbers per unit redshift, n_{21}, at $z = 0.1$ as $0.008^{+0.005}_{-0.004}$ from their QGP observations. This is lower than what has been found from the high-z Mg II absorbers and DLAs. This along with the observed redshift evolution of galaxy size and luminosity may suggest an evolution in the correlation between optical luminosity and the extent of the H I gas around galaxies with redshift.

Cold H I gas in strong Fe II absorbers

Absorption lines seen in the spectra of distant quasars allow one to probe the physical, chemical and ionization state of the intervening gas. In particular, absorption lines originating from fine-structure levels and hyper-fine-structure levels of atoms (such as C I, C II, O I and Si II), as well as ro-vibrational levels of molecules (such as H_2, HD, CO and OH), allow one to probe the physical state of the various gas phases (diffuse atomic, translucent and dense molecular) that constitute the interstellar medium (ISM). It is well known that the multiphase structure of a galaxy ISM is created and maintained by feedback processes related to the in-situ star formation. Hence, understanding the physical conditions and volume filling factors of the various ISM phases is extremely important since the ISM mediates between stellar-and galactic-scale processes. Moreover, detecting tracers of the various gas phases at different redshifts is necessary for mapping the redshift evolution of galaxies.

Damped Lyα systems (DLAs), with N(H I) $\geq 2 \times 10^{20}$ cm^2, have long been identified as good tracers of the ISM of high-redshift precursors of present day galaxies. Molecular H_2 absorption at optical wavelengths and H I 21-cm absorption at radio wavelengths are known to be excellent tracers of the cold neutral medium (CNM) phase of galaxies. However, systematic survey of H_2 absorption in DLAs using VLT/UVES and 21-cm absorption searches in DLAs using GMRT and GBT have demonstrated that systems selected solely on the basis of DLAs predominantly trace the diffuse warm atomic gas phase (T $\sim$ few 1000 K). Such studies indicate that the volume filling factor of cold neutral gas (T$\sim$ few 100 K) in DLAs may be very small (10-20%). Hence, selection only on the basis of presence of DLA has not proved to be an efficient way to probe the translucent and dense molecular phases in the ISM of high-z galaxies.

Due to the atmospheric cutoff, it is not possible to spectroscopically detect DLAs at $z < 1.7$ using ground-based telescopes, and a large space-based UV spectroscopic search for DLAs is difficult. Only $\sim$ 50 DLAs are known at $z < 1.7$ in contrast to more than thousand DLAs detected at $z \geq 2$ using SDSS. However, Rao et al. (2006) have demonstrated that Mg II and Fe II absorption can be used to pre-select DLAs. They detect DLAs with a success rate of $\sim$42% by selecting strong Mg II absorbers (rest equivalent width of Mg IIλ2796, $>$ 1Å) with W(Mg IIλ2796)/W(Fe IIλ2600) <2 and W(Mg I 2852) $>$ 0.1Å. Using strong Mg II systems having measurements of both N(H I) and W(Mg II) at $z < 1.65$ and $z \sim 2$, **Rajeshwari Dutta, R. Srianand, Neeraj Gupta, Ravi Joshi** and their collaborators have found that the probability of having log N(H I) $\geq$ 20.3, can be increased by a factor of $\sim$1.4-1.7, by selecting strong Fe II systems with W(Fe IIλ 2600) $\geq$ 1 Å. Hence, they have searched for H I 21-cm absorption in a sample of strong Fe II systems at $0.5 < z < 1.5$ selected from

SDSS-DR12, using GMRT and GBT. They have detected H I 21-cm absorption in six of these systems (see Figure 14).

Combining their sample with that of strong Fe II systems from the literature, they have estimated the detection rate of H I 21-cm absorption in strong Fe II systems to be 0.30±0.12 for limiting $\int \tau dv$ = 0.3 kms^{-1}. They have found that the detection rate increases with W(Fe II), being four times higher in systems with W(Fe II) $\geq$ 1 Å compared to the systems with W(Fe II)$<$ 1 Å. The detection rate of H I 21-cm absorption in strong Fe II systems remains constant within the uncertainties over $0.5 < z < 1.5$. For the spin temperature, T_s = 500 K (typical of DLAs at this redshift range) and unit covering factor, all the H I 21-cm absorption in strong Fe II systems would arise from DLAs. Hence, a W(Fe II) based selection appears to be efficient in detecting high N(H I) cold gas. From this they estimate the detection rate of H I 21-cm absorption in DLAs to be 0.67±0.31 at $0.5 < z < 1.5$. This is three times higher than that estimated in $2 < z < 3.5$ DLAs and may indicate towards an increasing filling factor of cold gas in DLAs with time.

The authors have not found any significant correlation of the H I 21-cm absorption strength with the metal line properties. However, the metal absorption are systematically stronger in the stacked SDSS spectrum of the systems, which show H I 21-cm absorption than in that of the H I 21-cm non-detections. In addition, the H I 21-cm absorbers tend to cause more significant reddening in the spectrum of the background quasars, and there is a tendency for the detection rate of H I 21-cm absorbers to be higher towards more reddened quasars. The stacked spectrum of quasars with HI 21-cm absorption detected towards them is more reddened than that of quasars without any H I 21-cm absorption. Hence, the above imply that H I 21-cm absorption is more likely to arise in metal-rich dusty cold gas. Note that highly reddened systems are likely to be missed out in samples selected on the basis of optical/UV spectra. Hence, upcoming blind H I 21-cm absorption surveys with the Square Kilometre Array precursors could unravel a new population of dusty absorbers towards highly reddened quasars.

By comparing the velocity widths of intervening H I 21-cm absorption lines detected in samples of QGPs, DLAs and Mg II systems at $z < 3.5$, **Dutta**, et al., have found evidence for the velocity widths to be increasing with redshift, which is significant at 3.8σ level. This could be because a typical H I 21-cm absorber may be originating from a larger mass galaxy halo at high z compared to at low z.

The Lyα emission from high-z galaxies hosting strong damped Lyα systems

Damped Lyα systems (DLAs) are the highest H I column density absorbers seen in QSO spectra, with N(H I) $\geq 2\times10^{20}$ cm^{-2}. These absorbers trace the bulk of the neutral hydrogen at $2 \leq z \leq 3$ and have long been considered to arise from the high-redshift precursors of present day galaxies. Presence of enriched elements, measured excitation of C II fine-structure levels, existence of a correlation between metallicity and the velocity spread of low-ion absorption lines akin to the mass metallicity relation seen in galaxies and rotational excitation of high J level of H_2 detected in a small fraction of DLAs , etc., suggest DLAs are associated in some way with star forming regions.

In order to probe the star formation in neutral gas clouds at high redshift, **Ravi Joshi, R. Srianand** and collaborators (Patrick Petitjean and Pasquier Noterdaeme) have performed a stacking analysis of 704 DLAs with a large H I column density (i.e., log N(H I) $\geq$ 21) and a median redshift of ∼2.7. They generated both emission and absorption line stacked spectrum for various sub-samples based on N(H I), z_{abs}, W_{1526} and $(r-i)$ colours of QSOs which led them to the following conclusions:

(1) For the full sample, they measured the Lyα luminosity of $(5.2 \pm 3.3) \times 10^{40}$erg s^{-1} when they integrated the luminosity over the full core regions of the DLA in the median spectrum. Similar values were obtained when they considered the stacked spectra obtained using weighted mean and 3σ clipped weighted mean. This luminosity is $\leq$ 0.1 per cent of the Lyα luminosity of $L_\star$ galaxies at these redshifts. In the bootstrap analysis, the measured luminosities in the red and blue part of the

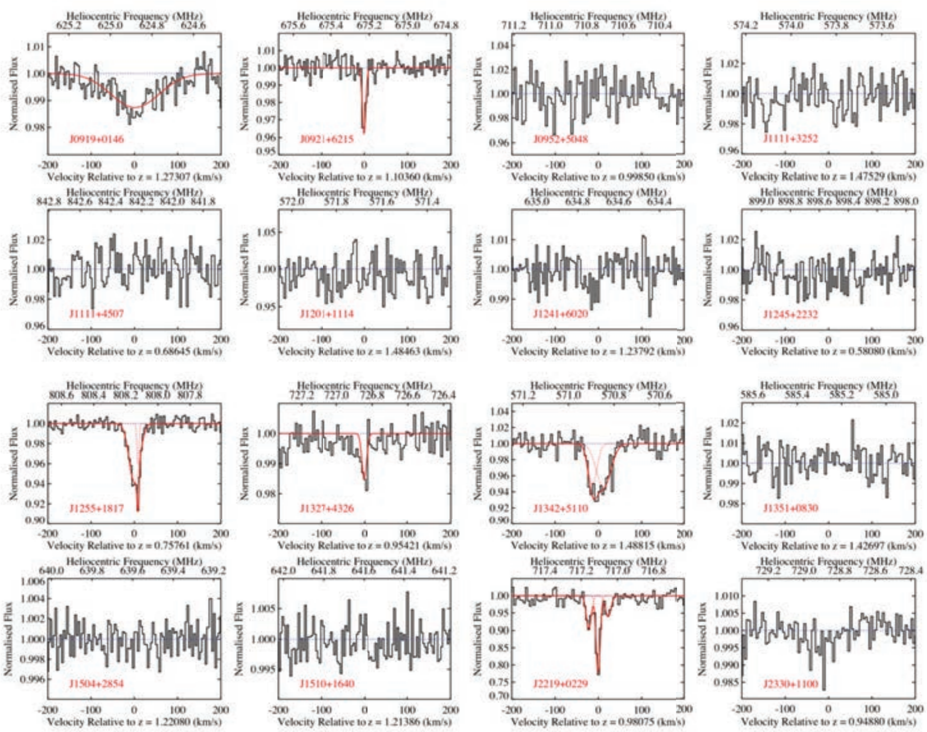


Figure 14: H I 21-cm absorption spectra towards the sample of strong Fe II systems, smoothed to $\sim$4 km s^{-1}. In the case of H I 21-cm absorption detections, individual Gaussian components and the resultant fits to the absorption profiles are overplotted as dotted and continuous lines, respectively.

core regions of the DLA troughs in the median stacked spectrum are $(-1.1 \pm 2.4) \times 10^{40}$erg s^{-1} and $(6.9 \pm 2.5) \times 10^{40}$erg s^{-1} respectively, with a $\sim$2.8 σ excess Lyα emission in the red part of the DLA trough.

(2) In the sub-samples based on W_{1526} they found the Lyα luminosities of $(13.5 \pm 4.1) \times 10^{40}$erg s^{-1} and $(14.6 \pm 5.5) \times 10^{40}$erg s^{-1} when they integrated the luminosity over the core of Lyα trough in the median spectrum for $W_{1526} \geq 0.4$ and 0.8 Å respectively. These luminosities are mainly contributed from the red part with respective luminosities of $L^r_\lambda = (12.3 \pm 2.9) \times 10^{40}$erg s^{-1} and $(12.1 \pm 3.9) \times 10^{40}$erg s^{-1}. Blue parts have luminosities consistent with zero. For systems with Si II, detections having $W_{1526} < 0.8$ Å they found the Lyα luminosity to be $(0.6 \pm 4.5) \times 10^{40}$erg s^{-1}. Even in this case most of the observed luminosity comes from the red part albeit with a significance of 1.3σ level. As the median N(H I) in all these sub-samples are the same, the difference in the Lyα luminosity are not likely related to the differences in the H I optical depth. Prochaska, et al. (2008) have found a strong correlation between W_{1526} and metallicity using echelle spectroscopic data. This correlation has been interpreted as a mass-metallicity relation as high W_{1526} absorption tend to trace low optical depth clouds in the halo or outflowing gas. Thus, the enhanced Lyα luminosity in the high W_{1526} could be an indication of high star formation in high metallicity systems together with easier escape of Lyα photos enabled by the large outflowing gas. They have measured large $b_{\rm eff}$ for systems with high W_{1526} which supports this hypothesis.

(3) The sub-samples based on N(H I) do not show any detectable difference in the measured Lyα luminosities either in the full core region or in the red part alone. The same is the case when we divided the sample into two redshift bins.

(4) The sub-samples based on $(r - i)$ colours and $W_{1526} > 0.4$ Å show a double hump profile for the low $(r-i)$ sub-sample (see Figure 15). The double hump disappears when more and more red QSOs sightlines are added to this sample. However, total Lyα luminosity does not show any monotonous trend with $(r-i)$. In addition, the $\mathrm{L}^{\mathrm{r}}_\lambda/\mathrm{L}^{\mathrm{b}}_\lambda$, FWHM and peak separation are intermediate between what is seen in LBGs and LAEs. However, to uniquely identify the reason behind the appearance of double humped Lyα line toward blue QSOs one needs detailed analysis of such individual systems using radiative transfer models. Establishing any trend between the dust indicators and Lyα profile will help us to discriminate between different models, such as (i) static medium, (ii) expanding/inflowing shell or (iii) multiphase media, of the Lyα radiative transport in DLAs. As these models predict different shape as a function of dust content.

(5) In their full sample as well as in all the sub-samples, they have detected Lyα emission predominantly in the red part of the Lyα through albeit with varied significance. The measured shift in the peak location of Lyα emission with respect to the absorption redshift is in the range 300-400 km s^{-1}. The redshifted profiles are typical of what is seen in the case of LBGs and LAEs at the same redshifts. In these cases, the observed redshifted Lyα profiles are considered as a signature of predominantly outflowing gas in these galaxies. Thus, the Lyα profile we measure in the case of high-z DLAs are consistent with the presence of outflowing gas. The measured shift in DLAs are higher than what is typically seen in LAEs but less than those of LBGs.

(6) Using the updated metagalactic UV background radiation contributed by QSOs and galaxies, they have found that the expected Lyα fluorescence is 4 to 10 times less than what they measure. This means most of the DLAs are not passive clouds in ionization equilibrium with the metagalactic UV background. Local excess ionizing radiation either from a nearby star forming region or from *in-situ* star formation is needed to produce the observed Lyα luminosities. They discussed different scenarios such as *in-situ* star formation in low luminosity galaxies or scattered Lyα emission from an extended Lyα halos around high luminosity galaxies as possible alternatively to explain the observed Lyα luminosity.

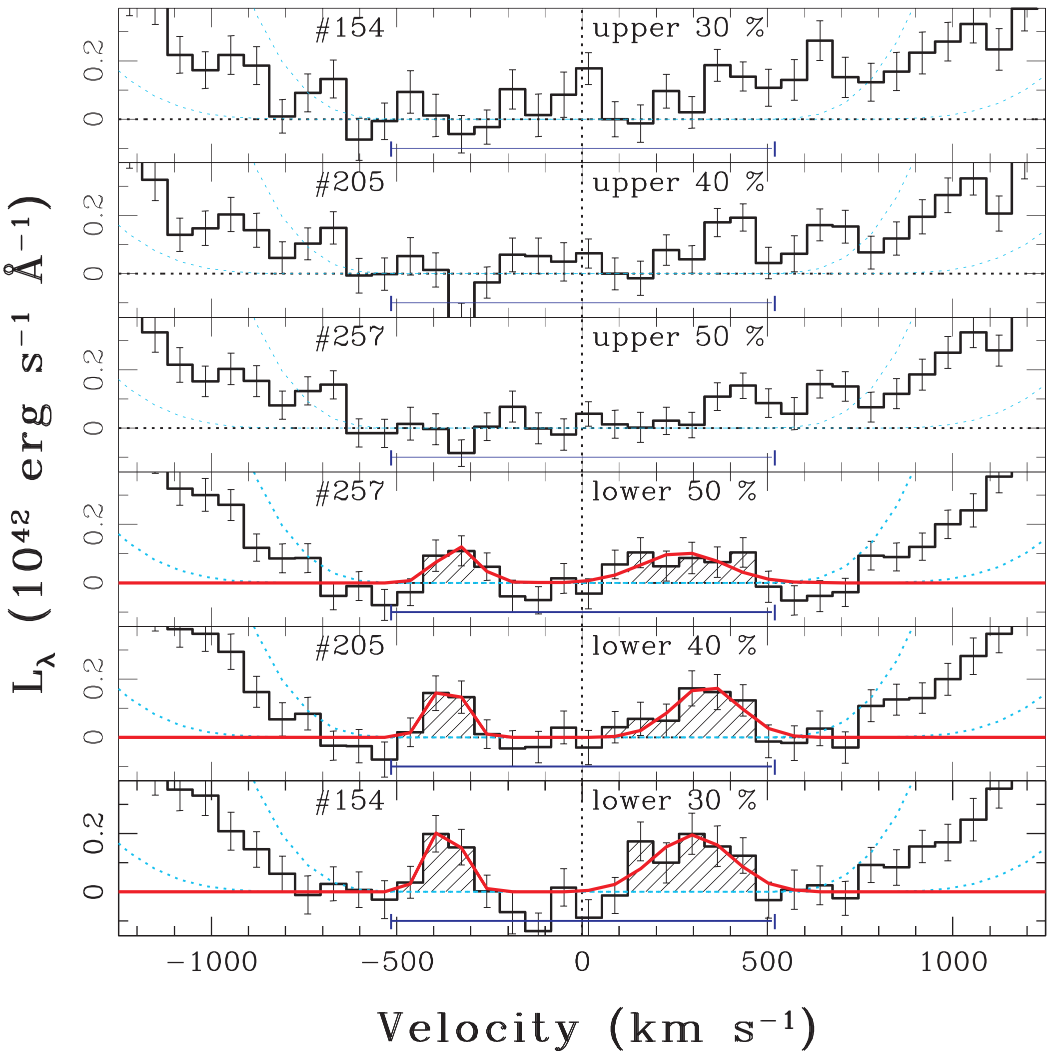


Figure 15: *Bottom to top:* The median stacked spectra for various sub-samples with $W_{1526} \geq 0.4$ Å with colour selection criteria of $(r-i) < 0.05, < 0.08, < 0.11, > 0.11, > 0.13$, and > 0.16. The blue segment shows the DLA core with $\tau \geq 10$ for log N(H I) = 21.0. The dashed curves show the synthetic profiles for lower (i.e., log N(H I)= 21) and median (i.e., log N(H I) = 21.23) column density of DLAs used to get the stacked spectrum. The solid red curves show the Gaussian fit to the non-zero flux seen in the red and blue part of the DLA core region. In each panel the number of DLAs contributing to the plot are also indicated.

Intergalactic Lyman continuum photon budget in the past 5 billion years

The H I photoionization rate ($\Gamma_{\rm HI}$) is usually constrained in the literature using three methods: (i) The first uses the H I absorption in the proximity of QSOs. The main uncertainties in this method arise because of the anisotropies in the QSO emission and possible density enhancements around the QSO host galaxies. (ii) The second method, mainly useful at low-z, is based on the measured Hα surface brightness from the outskirts of nearby galaxies ($z \sim 0$) and high velocity cloud at the edges of our galaxy. However, this measurement too is uncertain because of the assumptions made about the geometries of the Hα emitting gas. (iii) The third method of constraining $\Gamma_{\rm HI}$ is by simulating the observed properties of the Lyα forest (far away from the proximity of QSOs) such as the H I column density distribution function (CDDF), the flux probability distribution function (PDF) and the flux power spectrum (PS). **R. Srianand** and his collaborators (Prakash Gaikwad, Tirthankar Roy Choudhury and Vikram Khaire of NCRA), have been mapping $\Gamma_{\rm HI}$ as a function of redshift using observed QSO spectra and hydrodynamical simulations (see Figure 16).

To validate their simulations, they first compared their results with those of other low-z simulations in the literature using three predictions: (i) Thermal history parameters: Our simulation predicts $T_0 \sim 5000$ K and $\gamma \sim 1.6$ in the redshift range $z = 0.1$ to 0.45. These values are shown to be insensitive to our choice of T_0 and γ at an initial redshift, $z_1 = 2.1$; (ii) Distribution of baryons in phase diagram at $z = 0$: They find ~ 34 per cent of baryons are in diffuse phase, ~ 29 per cent in Warm Hot Intergalactic Medium (WHIM), ~ 18 per cent in hot halo and ~ 19 per cent in condensed phase, and (iii) The correlation between baryon overdensity Δ vs H I column density, $N_{\rm HI}$, in the redshift range $0.2 < z < 0.3$: we find $\Delta = 34.8 \pm 5.9\,(N_{\rm HI}/10^{14})^{0.770\pm0.022}$. They have shown that all these predictions compare well with those of low-z simulations in the literature that include different feedback processes at various levels. Feedback processes such and galactic winds or AGN feedback are not incorporated in this simulations. However, as shown by Shull, et al. (2015), these processes are not expected to severely influence $\Gamma_{\rm HI}$ constraints. The authors' method is computationally less expensive and allowed them to quantify various statistical and systematic uncertainties associated with the $\Gamma_{\rm HI}$ measurements.

For fair comparison, they mimic the simulated Ly α forest as close to observations as possible in terms of SNR, resolution and line spread function. The spectra generated are remarkably similar to the observed spectra. They have used two statistics that avoid voigt profile decomposition of the spectra (i.e., flux PDF and PS) and χ^2 minimization using appropriate covariance matrices to compare the observations with the model predictions. Using simulated data they showed that these two statistics are good in recovering the $\Gamma_{\rm HI}$.

The main results of their work are as follows:

1. They measured $\Gamma_{\rm HI}$ in four different redshift bins (of $\Delta z = 0.1$) centered at $z = 0.1125, 0.2, 0.3, 0.4$ using joint constraints from the two statistics mentioned above. Associated errors are estimated by varying thermal history parameters, cosmological parameters and continuum fitted to the observed spectrum. Due to limited wavelength range covered in the HST-COS spectrum used, the $\Gamma_{\rm HI}$ measurement for the highest redshift bin (i.e .,$z = 0.4$) is likely to be affected by the contamination of Lyβ forest absorption from higher-z. They contaminated their simulated Ly α forest at $z = 0.4$ by Ly β forest from $z = 0.6$ and corrected for the effect of Ly β contamination in their $\Gamma_{\rm HI}$ measurement for this z bin. The measured Γ_{12} values at redshift bins $z = 0.1125, 0.2, 0.3, 0.4$ are 0.066 ± 0.015, 0.100 ± 0.021, 0.145 ± 0.037, 0.210 ± 0.052 respectively.

2. Final quoted errors in the $\Gamma_{\rm HI}$ measurements include possible uncertainties coming from the statistical uncertainty (~ 14 per cent), cosmic variance (~ 3 per cent), cosmological parameters uncertainty (~ 10 per cent) and continuum uncertainty (systematic uncertainty ~ 7 per cent). Uncertainty in $\Gamma_{\rm HI}$ due to uncertainty in thermal history parameters, over the

range considered here, is small and within statistical uncertainty.

3. As expected based on UVB models, even in the small redshift range covered in our study, the measured $\Gamma_{\rm HI}$ shows a rapid evolution with z. They fit the redshift evolution of Γ_{12} as $\Gamma_{12} = 0.040 \pm 0.001\,(1+z)^{4.99\pm0.12}$ at $0.075 \leq z \leq 0.45$.

4. The $\Gamma_{\rm HI}(z)$ obtained are consistent with the measurement of Shull, et al. (2015) however, this $\Gamma_{\rm HI}$ measurement at $z = 0.1$ is factor ~ 2.7 smaller than Kollmeier, et al. (2014). Note these two earlier measurements used H I column density distribution to constrain $\Gamma_{\rm HI}(z)$. As a consistency check, the authors have Gaikwad et al., showed the H I column density distribution predicted by their simulations, for the best fit value of $\Gamma_{12}(z)$, matches well with the observed distribution.

5. The $\Gamma_{\rm HI}$ measurement at any z_1 depends on the emissivities of the ionizing sources at $z \geq z_1$ and Lyman continuum opacity of the IGM. Gaikwad, et al., have considered the updated emissivities of QSOs and galaxies (with $f_{\rm esc}$ as a free parameter) and two different H I column density distribution as a function of z and obtained $\Gamma_{\rm HI}$. They find that the derived $\Gamma_{\rm HI}(z)$ is consistent with being contributed only by QSOs. This is true even if they allow for variations in the UV spectral index, of QSOs. They also find the maximum 3σ upper limit on $f_{\rm esc}$ at $z < 2$, allowing for uncertainty in FUV spectral index and cloud distribution $f(N_{\rm HI}, z)$ is 0.008. This is consistent with 3σ upper limits on average $f_{\rm esc}$ (i.e., ≤ 0.02) obtained by stacking samples of galaxies probing average galaxy mass $M \geq 10^{9.3} M_\odot$.

   The authors' measurements suggest that the contribution of low mass galaxies to average $f_{\rm esc}$ will also be small. The study confirms that there is no crisis at low redshift in accounting for the observed Lyman continuum photons using standard known luminous astronomical sources. Thus, $\Gamma_{\rm HI}(z)$ measurement can in turn be used to place a strong constraint on the contributions of decaying dark matter to the low-z UVB.

On the ionization state of Ne VIII absorbers

Ne VIII absorbers seen in QSO spectra are useful tracers of warm ionized gas, when collisional ionization is the dominant process. While photoionization by the ultraviolet background (UVB) is a viable option, it tends to predict large line-of-sight thickness for the absorbing gas. Understanding the source of ionization of Ne VIII absorbers is important for understanding the missing baryons problem. **R. Srianand, Tanvir Hussain** and collaborators (Vikram Khaire, Sowgat Muzahid and Phatak) revisited the photoionization origin of Ne VIII absorbers using their updated UV background, and reanalyse the interveing Ne VIII absorbers. The important conclusions are summarized as follows:

1. Ne VIII and O VI are simultaneously reproduced in a photoionized gas having total hydrogen densities of $n_H = 4\times10^{-5}$ to 8×10^{-6} cm^3. This, in comparison to previous estimates, is a factor of $\sim$3 higher. Also, except for a few, all these photoionized absorbers require near solar to supersolar metallicities. The line-of-sight thickness measured for these Ne VIII systems is $l < 100$ kpc (except for one absorber with $l = 299$ kpc) favouring a photoionized origin for all these absorbers. This is unlike, what have been found from previous studies of the Ne VIII absorbers, where photoionization was ruled out purely based on large line-of-sight thickness ($>$ 1 Mpc) of the cloud.

2. They showed that the collisionally ionized gas with solar metallicity and having density above critical density can cool within 10^8 yrs. This will make the detectability of the collisionally ionized Ne VIII phase difficult, unless there is a constant heating source present in the system. The cooling issue can be sorted out if the gas phase metallicity is lower. In a couple of cases, broad Lyα (BLA) associated with the Ne VIII absorbers have been reported. The inferred N (H I) is consistent with collisional ioniza-

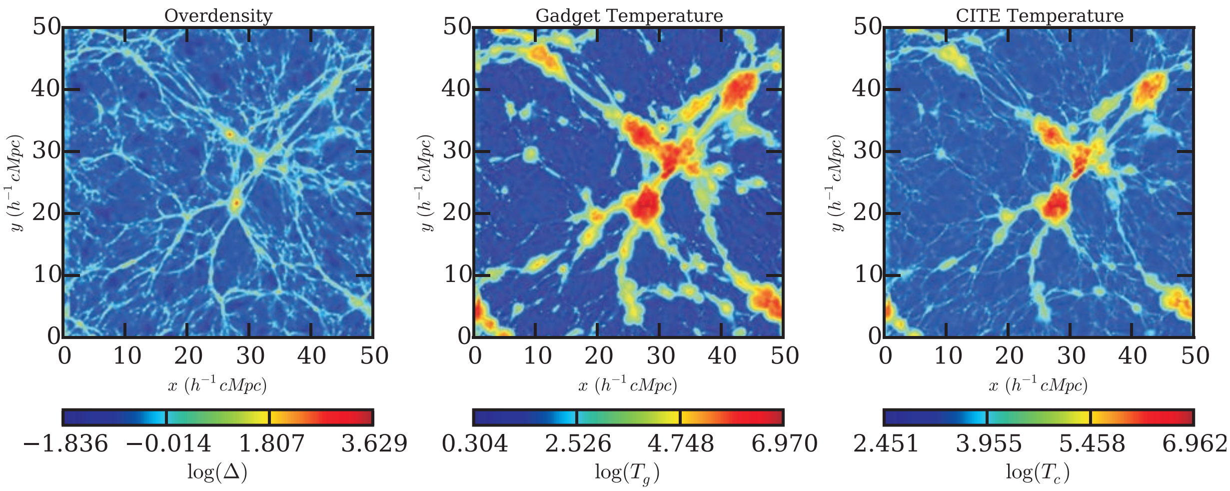


Figure 16: Two-dimensional slices of width 0.1 h^{-1} cMpc obtained from the GADGET-2 output snapshot at $z = 0.3$. *Left-hand panel:* The distribution of baryon overdensity Δ. Colour scheme is such that red and blue represent highest and lowest density regions respectively. *Middle panel:* The gas temperature T_g from GADGET-2. *Right-hand panel:* The gas temperature T predicted after evolving the temperature from $z_1 = 2.1$ (initially at z_1, $T_0 = 15000$ K and $\gamma = 1.3$) using our post-processing module CITE. The highly overdense regions are at higher temperatures because of the shock heating resulting from the structure formation. The colour scheme in middle and right-hand panel is such that red and blue correspond to highest and lowest temperature regions respectively.

tion of Ne VIII gas when the gas phase metallicity is less than that of the low ion phase. In such cases, collisions are possible. Therefore, accurate determination or constraints of BLA absorption associated with the Ne VIII phase is important to distinguish between photoionization and collisional ionization models. Mere line-of- sight thickness arguments cannot rule out the photoionized origin of the Ne VIII phase.

3. Photoionized Ne VIII absorbers probe 0.5 per cent of the cosmic baryon density as compared to what have been reported for collisionally ionized Ne VIII gas ($\sim$ 4 per cent). This is because these photoionized absorbers have 10 times less total hydrogen column densities, log N(H) = 17.5−19.0 cm^{-2} as compared to what one obtains from collisional ionization models.

Quasars, Active Galactic Nuclei and Absorption Systems

The cold neutral and molecular gas phase in the interstellar medium (ISM) and the circumgalactic medium (CGM) of galaxies are very important because it acts as the reservoir for star formation. The inverse dependence of the H I 21-cm optical depth on the spin temperature (and hence the gas kinetic temperature), along with its resonance frequency falling in the radio wavelengths, make the H I 21-cm absorption line a good tracer of high column density cold H I gas without being affected by dust and luminosity biases. **Rajeshwari Dutta** et al. have used H I 21-cm absorption to characterize the cold ($T \sim 100$ K) gas in and around galaxies, both at low and high redshifts. To obtain the 21-cm absorption spectra, we have carried out observations using radio interferometers like the Giant Metrewave Radio Telescope (GMRT), the Very Large Array (VLA) and the Greenbank Telescope (GBT).

The main results from low redshift ($z < 0.4$)

studies are: (i) Both the absorption strength and covering factor of H I 21-cm absorbers around galaxies decline weakly (at 2.4σ significance level) with increasing impact parameter and radial distance from the galaxy centre. (ii) The distribution of H I 21-cm absorbers around galaxies is likely to be co-planar with the H I discs. (iii) No significant dependence of the strength and distribution of H I 21-cm absorbers is found on the host galaxy properties like luminosity, stellar mass, colour and star formation rate. (iv) The cold H I gas around galaxies is likely to exist in the form of small clumpy clouds that are distributed patchily.

The main results from high redshift ($0.5 < z < 1.5$) studies are: (i) **Dutta** et al. have shown that strong Fe II systems have high probability of harbouring high column density cold H I gas. The detection rate of H I 21-cm absorption increases with the strength of Fe II absorption. (ii) Cold gas detected in H I 21-cm absorption are closely linked with the metal and dust content of the gas. H I 21-cm absorption arises on an average in systems with stronger metal absorption and towards quasars which are systematically more reddened. (iii) The velocity width of H I 21-cm absorption lines detected in absorption and galaxy-selected samples shows an increasing trend (significant at 3.8σ) with redshift, which could imply that the typical H I 21-cm absorber may be probed by larger mass galaxy halos at high-z (for a given metallicity). (iv) We do not observe any significant evolution in the detection rate and number density per unit redshift of H I 21-cm absorbers in strong Mg II systems over $0.3 < z < 1.5$. However, the cold gas fraction in Damped Lyman-α absorbers maybe increasing from $z > 2$ to $z < 1$ by a factor of $\gtrsim 3$.

Origin of spiral structure

The aim of this project has been to understand how the spiral structures arise in galaxies and how are they maintained for billions of years - which itself is an outstanding issue in galaxy dynamics for the last 50-60 years. **Kanak Saha** and Bruce Elmegreen have used N-body simulations as a primary tool to investigate this phenomenon. Recently, we have reported how two-armed spiral structure can be spontaneously generated and maintained for about 4 - 5 billion years in the presence of an intermediate-mass bulge. If there is an inner Lindblad resonance (ILR), an in-ward propagating spiral structure would be absorbed. The intermediate bulge produces a Q-barrier, shielding the ILR and reflecting the in-ward moving wave. This reflected wave is swing-amplified and manifested as a two-armed spiral structure in the galaxy. We are currently investigating several other routes. We have showed for the first time, a long-lived two-armed spiral in a disk galaxy in a self-consistent 3-D simulation.

Galaxy formation and evolution using UVIT/AstroSat

Galaxies grow either by merging with other smaller galaxies, accreting materials and/or by forming stars. It is well known that in order to grasp the recent star formation activity it is best to observe in the UV band (120 - 300 nm), which requires observation from space. **Kanak Saha** has used the unique opportunity of AstroSat and proposed to carry out a deep UV survey of the sky about 1200 sq. arcmin area covering the extended Chandra Deep Field South/Hubble Deep field. UVIT provides a factor of 3 better resolution over the NASA's GALEX satellite and also higher sensitivity, which means UVIT will resolve sources that GALEX cannot. (see Figure 18 In addition, UVIT can go about 2 mag deeper, enabling detection of faint UV sources in the Chandra Deep Field South. This is extremely helpful in deciding the faint-end slope of the UV luminosity function.

Classical bulges in S0 galaxies: Being low mass is complicated

The matter of formation and evolution of S0 galaxies is further complicated by the fact that they have bulges of two types: Classical and pseudo-bulges. In a recent study about classical bulges in lenticular (S0) galaxies, **Sheelu Abraham**, Sudhanshu Barway, Yogesh Wadadekar and **Ajit Kembhavi** have showed that the classical bulges in high mass S0s have properties similar to elliptical galaxies, while those in low mass S0s have more complex proper-

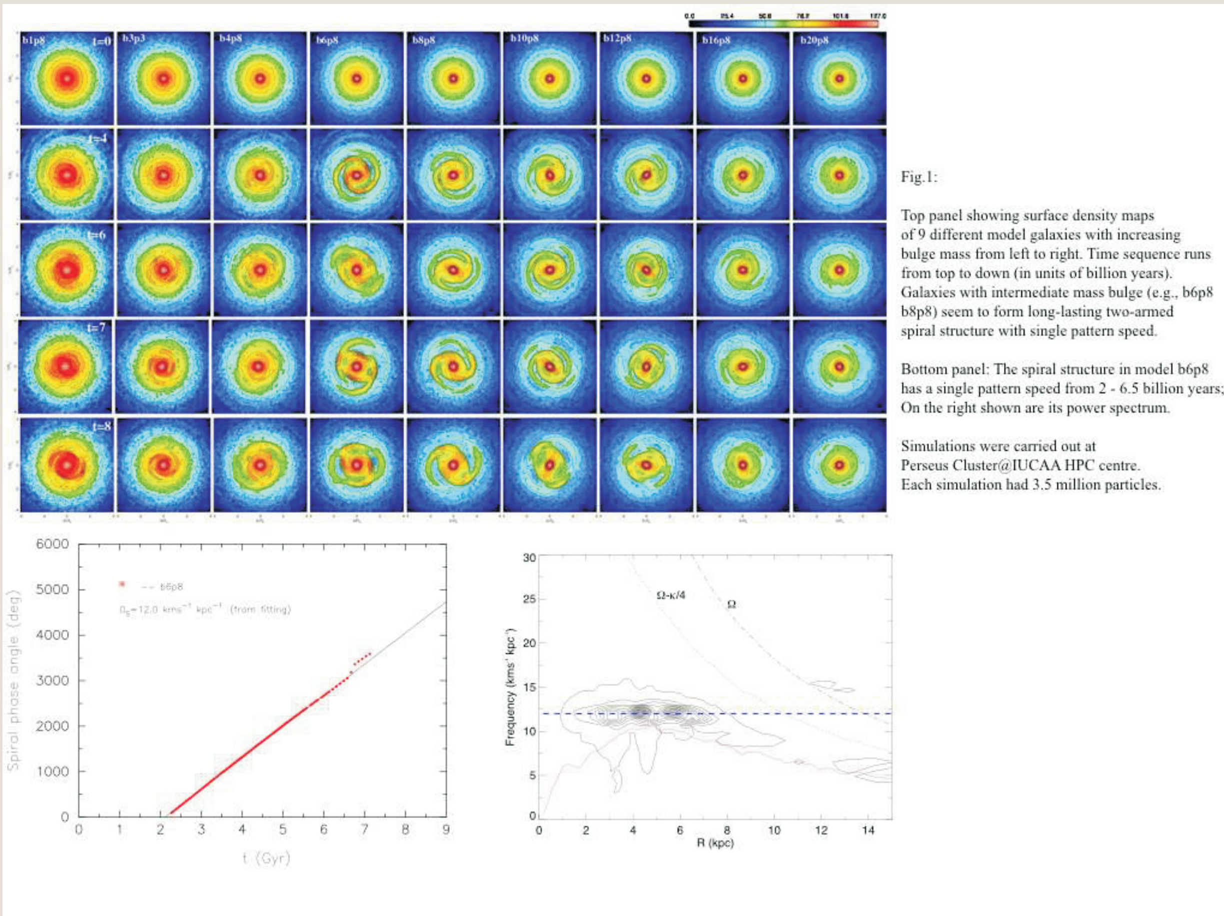


Figure 17: Top panel showing surface density maps of 9 different model aglaxies with increasing bulge mass from left to right. Time sequence runs from top to down (in units of billion years). Galaxies with intermediate mass bulge (e.g., b6p8 b8p8) seem to form long-lasting two-armed spiral structure with single pattern speed. Bottom panel: The spiral structure in model b6p8 has a single pattern speed from 2- 6.5 billion years: On the right shown are its power spectrum. Simulations were carried out at Perseus Cluster@IUCAA HPC centre. Each simulation had 3.5 million particles.

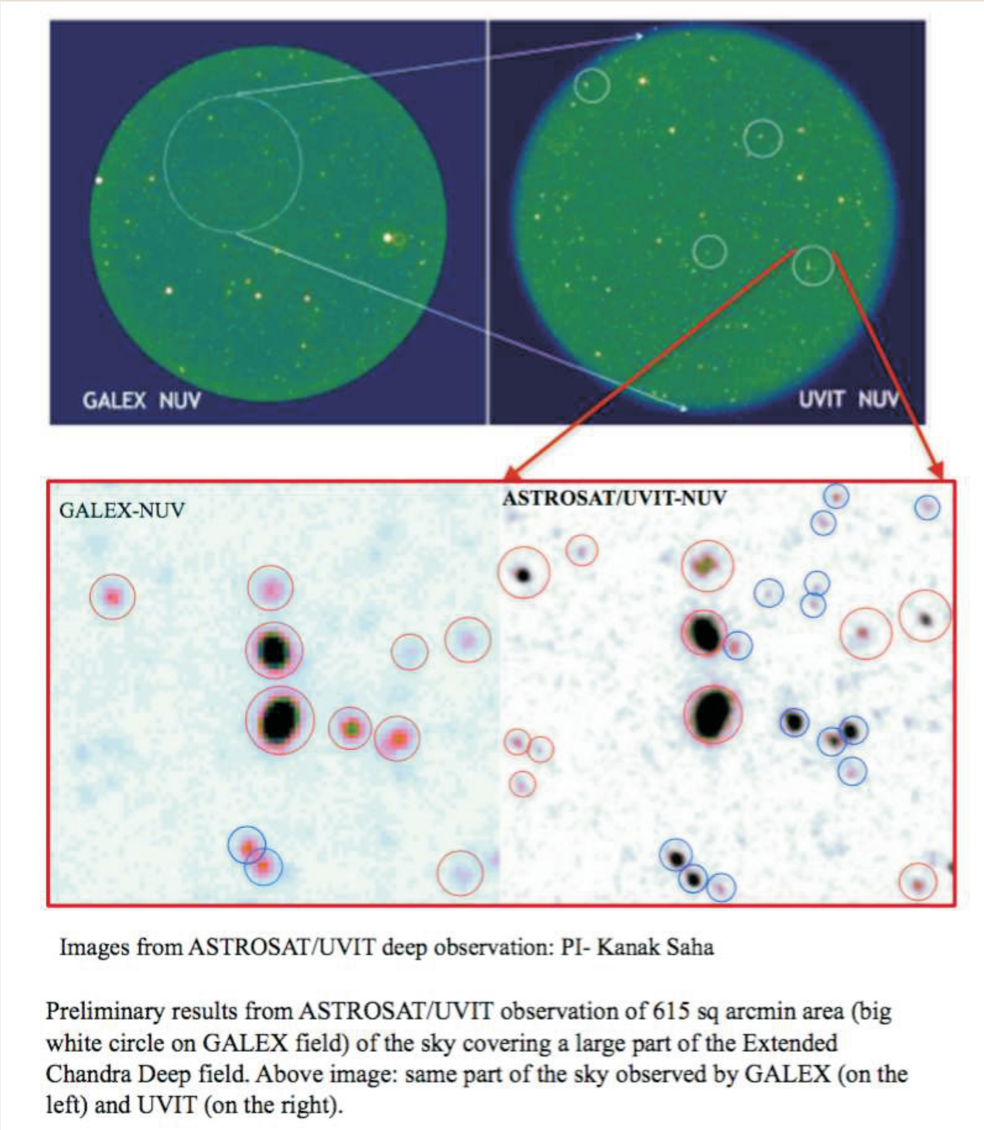


Figure 18: Preliminary results from AstroSat/ UVIT observation of 615 sq arcmin area (big white circle on GALEX field) of the sky covering a large part of the Extended Chandra Deep filed. Above image: same part of the sky observed by GALEX (on the left) and UVIT (on the right).

ties, which point to a different formation history. They have derived the structural parameters for 305 S0 galaxies and studied the correlations of different structural parameters using bulge-disk-bar decompositions on SDSS DR7 r-band images. A combination of bulge Srsic index, and the location of the galaxy bulge on the Kormendy diagram is used to separate the bulge into the two types. Using multi-band photometry, they use SED fitting techniques to estimate the masses of the sample galaxies, and divide the sample galaxies into high-mass and low-mass subsets. While the bulges of the high-mass S0 galaxies follow the same scaling relations as ellipticals, the bulges of low mass S0 galaxies show greater scatter, and the host galaxies come with mixed stellar populations, and a high fraction shows evidence of recent star formation. The bulges of high mass S0s are likely to have formed in the same manner as ellipticals, while the bulges of low mass S0s appear to share the properties of classical and pseudo-bulges, with more than one process contributing to their origin.

Detection of bars in galaxies with Deep Convolutional Neural Network

The current era of astronomy has to face the challenge to handle an accelerating explosion of data. Conventional methods of analysing the data have become impractical, and so people have started implementing different algorithms for the purpose. One of the breakthrough technologies that has been transforming the computer vision field is Deep Learning, and soon the computing applications will completely change the world. These techniques can be applied to solve problems in astronomy (Dieleman, et al. (2015)). **Sheelu Abraham**, Arun Kumar Aniyan and **Ajit Kembhavi** have developed a method based on deep learning application for detecting bars in galaxies. Bars are the prominent feature in most of the disc galaxies. Various studies and simulation works show that bars play an important role in the evolution of host galaxies and so it is important to understand their distribution. In this work, they have used a multi-layer neural network called Convolutional Neural Network (CNN) for the classification of barred and unbarred galaxies. Data used for this study is taken from Sloan Digital Sky Survey DR13. The network can automatically detect the features within the images. The network is trained with a well-defined sample of barred and unbarred galaxies using images from SDSS. All the samples are visually examined before using as a training sample. They are able to classify the barred and unbarred samples with 94% accuracy using CNN. The trained network can be applied to a larger sample to classify barred and unbarred galaxies, where there is no such information is available for the sample.

Using an optically selected, statistically complete sample of 53 nearby groups (CLoGS), observed at both radio (GMRT) and X-ray (Chandra and XMM-Newton) frequencies, **Konstantinos Kolokythos** aims to characterize the radio-AGN population in groups and examine their impact on the intra-group gas and member galaxies. The author has used the sensitivity to older electron populations at 235 MHz and the resolution of 610 MHz as a key to identify past and current AGN activity first results from low-frequency GMRT radio images of the nearby (< 80 Mpc) central brightest group elliptical from the high richness CLoGS sub-sample. Further, the study includes the properties in radio that central group galaxies present in the sample (radio morphology, spectral index, energetics, etc.), along with information on the group environment that they lie into, in combination with findings from X-ray observations.

2) Also, the author has been involved in XXL-N GMRT project that currently is putting together a catalog of radio sources.

3) In the ongoing radio study of NGC 5903, a very interesting system that presents HI and continuum radio sources, we have determined the recent history of interactions in the group.

Giant Radio Galaxies

Giant radio galaxies (GRGs) and radio quasars (GRQs) represent an extreme class of active galaxies with linear sizes in the range 0.7 to 5 Mega parsecs, thus placing them amongst the largest single astrophysical objects in the sky. The first GRG, 3C236, discovered 40 years ago, about 5 Mpc across, is one of the extremely large GRGs. Since then, only a few other GRGs have been reported exceeding 1 Mpc. The largest known GRG to date is J1420-0545, which spans also about 5 Mpc across. Despite various studies on GRGs, no unified model has emerged that can explain the immense size and other physical properties of this extreme class of radio galaxies. Despite many observations and various theoretical models proposed, the mechanisms by which the relativistic jets are launched from the accretion discs around massive black holes in AGNs are very poorly understood. To date, very few theoretical models have been proposed to explain the growth of GRGs to such enormous sizes. One of the common explanations for their gigantic size is attributed to the less dense IGM around them, which allows them to expand and grow unhindered. This implies that GRGs are preferentially born in sparser galactic environments. Another theory proposes that GRGs are very old objects and thus have grown to their current sizes over very long time-cales. This implies that AGNs in GRGs remain active for much longer time scales. **Pratik Dabhade**, along with **Joydeep Bagchi**, **Somak Raychaudhury** and collaborators has undertaken a detailed multifrequency study of a large sample of GRGs in order to examine these prevailing theoretical models.

We have carried out an extensive search for large (Mpc) scale double radio sources. This was done by careful visual inspection of publicly available radio maps in NVSS (NRAO VLA Sky Survey). Under this project we are for the first time aiming to make a sample of all known GRGs and also discovering hundreds of new GRGs from the existing survey data. We perform not only multifrequency radio studies but also multi-wavelength studies of galactic hosts of our GRGs. The criteria adopted for source selection is as follows:

1. Double radio sources with angular size greater or equal to 3 arcmins.
2. Proper identification of host of the GRG/GRQ by overlaying radio and optical maps. Confirmation of coincidence of radio core and host galaxy/quasar as seen in optical.
3. Availability of reliable redshift (spectroscopic or photometric) information of the host galaxy from various optical surveys.
4. Overall physical sizes greater or equal to 700 Kpc.

Optical data was mainly taken from SDSS (Sloan Digital Sky Survey) followed by 6dFGS (6 Degree Field Galaxy Survey) and 2MASS (2 Micron All Sky Survey). Our discovery sample of GRGs was also explored in other radio surveys like FIRST (Faint Images of the Radio Sky at Twenty-cm), TGSS (TIFR GMRT Sky Survey), WENSS(Westerbork Northern Sky Survey) and SUMSS (Sydney University Molonglo Sky Survey) for additional information at more frequencies.

Result highlights

1. Till date we have found $\sim$ 160 new GRGs after having searched $\sim$ 1200 square degree area of NVSS.
2. A complete catalogue of all known GRGs (published between 1974 to 2017) was compiled with uniform parameters.
3. Using mid-infrared WISE colour data, classification of the accretion state of black hole (into high excitation or low excitation states) was done.
4. Additionally, 150 new GRGs were discovered from the LOFAR Two Metre Sky Survey (LoTSS), which is a sensitive survey at 150 MHz frequency, carried out with LOFAR (Low Frequency Array) telescope. This work was carried out in collaboration with University of Leiden (Netherlands) radio astronomy group.

A peculiar giant radio galaxy in a cluster with striking 'kink' features

In the course of identifying giant radio galaxies and carrying out their detailed multi-wavelength

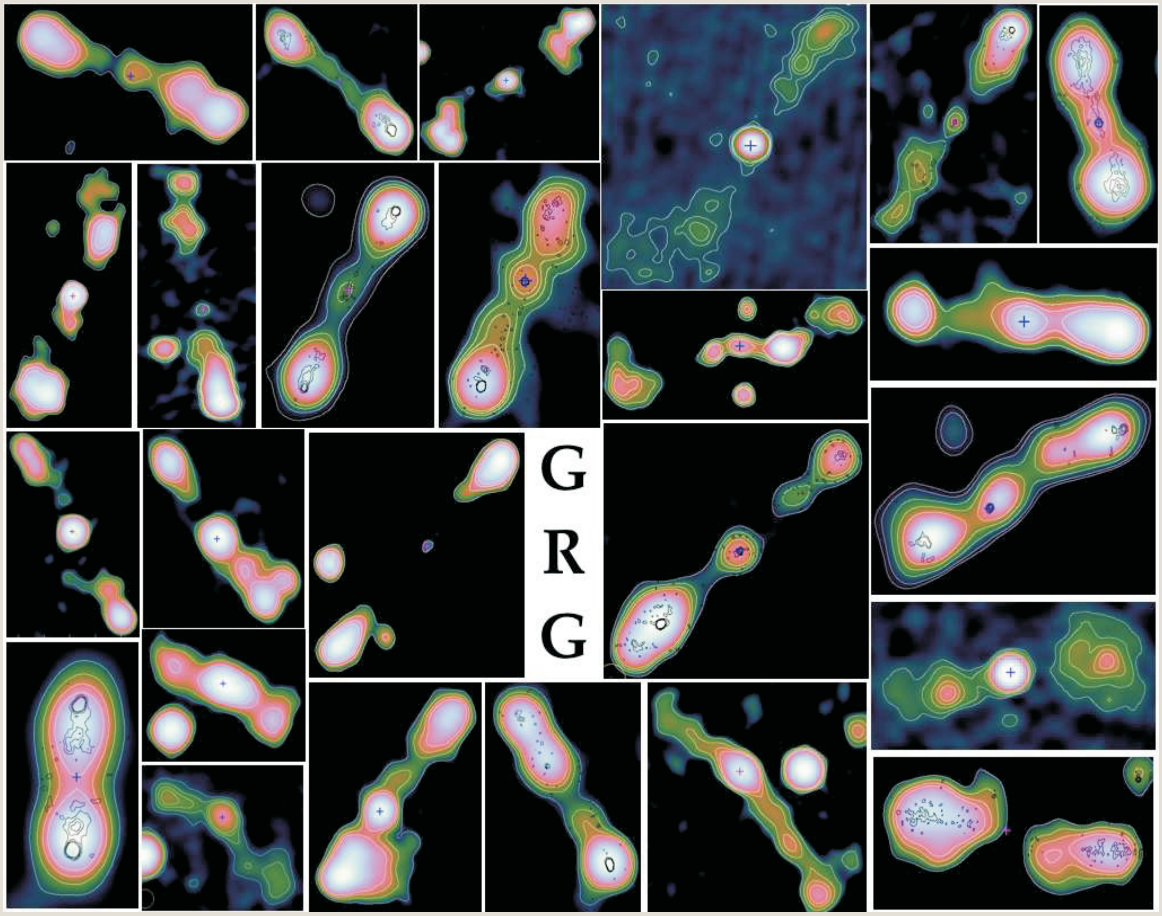


Figure 19: Radio images of all 25 GRGs from 1.4 GHz NVSS survey reported in our first paper shown in montage format. The low resolution (45 arcsec beam) images are shown in colour. High resolution (5 arsec beam) structures of these GRGs are shown in black contours, taken from VLA FIRST survey.

studies, **Pratik Dabhade, Joydeep Bagchi, Somak Raychaudhury** and collaborators discovered a peculiar giant radio galaxy J223301+131502 from the 1.4 GHz NRAO VLA Sky Survey. GRG J223301+131502 is about 15 arcmin in angular size (Figure 20), which assuming standard cosmology translates to linear size of $\sim$ 1.7 Mpc at a redshift of 0.093. Its radio power at 1.4 GHz is $\sim 0.40 \times 10^{25}$ W Hz^{-1}. The host galaxy of this GRG is the brightest cluster member (BCG) of the cluster J223301.30+131502.5, listed in WHL cluster catalogue. The cluster has the following properties: radius $R_{200} = 1.02$ Mpc; mass $M_{200} = 1.1 \times 10^{14} M_{\odot}$; X-ray luminosity $L_X = 0.4 \times 10^{44}$ erg/s (in the 0.1-2.4 keV band) and temperature $T_X = 2.3$ KeV. This GRG, therefore, challenges one of the common beliefs that systems of this class attain their gigantic sizes due to their preferential location in a sparse galactic environment. This suggests that environment alone may not play a primary role in growth of the GRGs, as commonly believed in previous works. Rather, a powerful AGN must be at work here. Radio lobes associated with AGN outbursts are commonly seen in BCGs, although on scales much smaller than GRG J223301+131502. These structures are typically tens of kpc across, with the record holder, MS0735.6+7421, having radio lobes roughly 200 kpc across. The radio plasma injected by the AGN in BCGs has been known to displace the ICM, giving rise to dark cavities devoid of X-ray emission. These cavities are believed to be one of the mechanisms by which the central massive black hole heats the surrounding medium, preventing runaway cooling and excessive star formation in cool-core clusters. Thus, GRG J223301+131502 offers us a unique opportunity to study such an extreme AGN outburst and its interaction with the relatively dense intra-cluster medium (ICM) around the BCG.

Apart from its unusual setting in a dense cluster environment, GRG J223301+131502 also presents a spectacular and puzzling morphology. The high resolution GMRT radio maps (Figure 20(a)&(b)) at 325 MHz ($\sim$ 9" resolution) and 610 MHz ($\sim$ 5" resolution) reveal a pair of highly collimated radio jets extending unhindered up to $\sim$ 400 kpc. On both sides of the black hole, the jets terminate in a pair of "kink" like structures before fading into huge flaring radio lobes. The "kink" feature on the western side, appears to be a rare form of plasma instability, measures about 100 kpc in size with a bright region on top. Further investigating these 'kinks' could provide compelling evidence for the interaction between the radio plasma and the surrounding ICM, allowing us to view both the formation of GRGs and the physics of AGN feedback in a new light. The bright 'kink' could correspond to 'impact surface' of a supersonic jet in which the bulk kinetic energy is converted into powerful shock waves. At such shock fronts formed in the jets, relativistic electrons are efficiently accelerated due to the impact on the ambient medium. While the 'kink' on the western side of the jet is prominently seen, the 'kink' on the eastern side fails to show the same morphology. We suspect the 'kinks' to be in different planes where only one of them is clearly distinct due to projection effects. As seen in Figure 20(c), the radio spectral index map shows the western kink to have a flat spectrum, which is a signature of a shock front and associated particle acceleration, which should be seen in our future X-ray images.

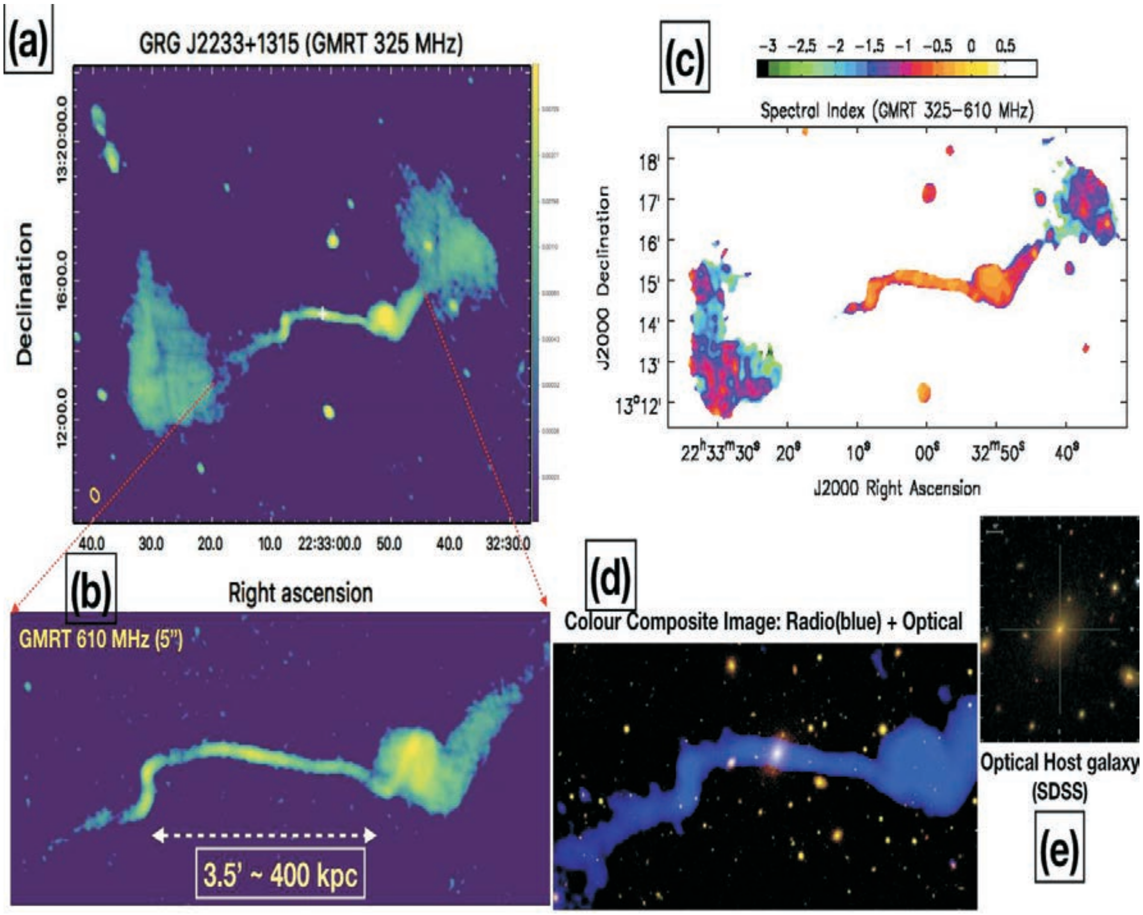


Figure 20: (a) GMRT 325 MHz image with $\sim 90\mu$ Jy/beam rms, (b) GMRT 610 MHz image with $\sim 30\mu$ Jy/beam rms, (c) A spectral index map between 325 and 610 MHz frequencies, (d) Radio (GMRT) image combined with optical (SDSS) image showing the host galaxy and (e) Optical colour image of host galaxy.

Zwicky's Nonet: A compact merging ensemble of nine galaxies and 4C 35.06, a peculiar radio galaxy with dancing radio jets

Galaxy mergers, which take place more frequently in the dense environments of galaxy clusters, play a pivotal role in the evolution of galaxies in the Universe. Mergers have profound effects on the properties of galaxies on various physical scales. On galactic scales (around 10 to 100 kpc), mergers may result in ram-pressure stripping of gas, the formation of long tidal tails and enhanced star formation activity. On smaller scales ($<$ 1 pc), the growth of black holes (BHs) and possible triggering of active galactic nucleus (AGN) activity with occasional relativistic jet ejection may occur in mergers. On the smallest scales ($<<$ pc), the final inspiral stage of merging black holes results in powerful gravitational wave emission, which is a very exciting emerging field of research. However, the formation and merger rates of galactic BHs are still very much uncertain. Finally, on very large scales (around 100 – 1000 kpc), the shocks and turbulence inducted into the intracluster medium (ICM) during mergers may inject large amounts of nonthermal energy and cause subsequent shock heating of the ICM to X-ray temperatures, with disruption of cooling cores. Therefore, cluster centres are fascinating laboratories in which we will be able to study galaxy formation, evolution and growth of black holes.

K.G. Biju, along with **Joydeep Bagchi, Pratik Dabhade, Sheelu Abraham, Samir Dhurde** and other collaborators report the results of extensive radio, optical and infrared studies of a peculiar radio source 4C 35.06, an extended radio-loud active galactic nucleus (AGN) at the centre of galaxy cluster Abell 407 (redshift z = 0.047). The central region of this cluster hosts a remarkably tight ensemble of nine galaxies, the spectra of which resemble those of passive red ellipticals, embedded within a diffuse stellar halo of $\sim$ 1 arcmin size (Figure 21) This system (named 'Zwicky's Nonet' to honour pioneer astronomer, late Fritz Zwicky, who first noticed this remarkable galactic system at Palomar) provides unique and compelling evidence for a multiple-nucleus cD galaxy precursor residing in a rich cluster environment. Multifrequency radio observations of 4C 35.06 with the Giant Meterwave Radio Telescope (GMRT) at 610, 235 and 150 MHz reveal a spectacular system of 400 kpc scale helically twisted and kinked radio jets and outer diffuse lobes (Figure 21). The outer extremities of jets contain extremely steep-spectrum (spectral index -1.7 to -2.5) relic or fossil radio plasma with a spectral age of few into $10^7 \sim 10^8$ year. Such ultra-steep spectrum relic radio lobes without definitive hotspots are extremely rare and they provide an opportunity to understand the life cycle of relativistic jets and physics of black hole mergers in dense galaxy environments. They interpret multiwavelength observations of this radio source in the context of growth of its central black hole, triggering of its AGN activity and jet precession, all possibly caused by galaxy mergers in this dense galactic system. A slow conical precession of the jet axis due to gravitational perturbation between interacting black holes has been invoked to explain the unusual jet morphology.

High Energy Astrophysics

Accretion disks in AGN

The accretion disks in active galactic nuclei (AGN) have been assumed to be the standard disk as theorized by Shakura and Sunyaev (1973). However, nature of real accretion disks in AGN is not well known. One way to probe if AGN hosts standard disk is to measure the time lag of optical/UV emission relative to the X-ray emission and study the wavelength dependence of the lag. **Main Pal Rajan, G. C. Dewangan**, S. D. Connoly and **Ranjeev Misra** have investigated the nature of accretion disk in a bare Seyfert 1 galaxy Fairall 9 using Swift monitoring observations consisting of 165 usable pointings spanning nearly two years and covering six ultraviolet (UV)/optical bands and X-rays. Fairall 9 is highly variable in all bands though the variability amplitude decreases from X-ray to

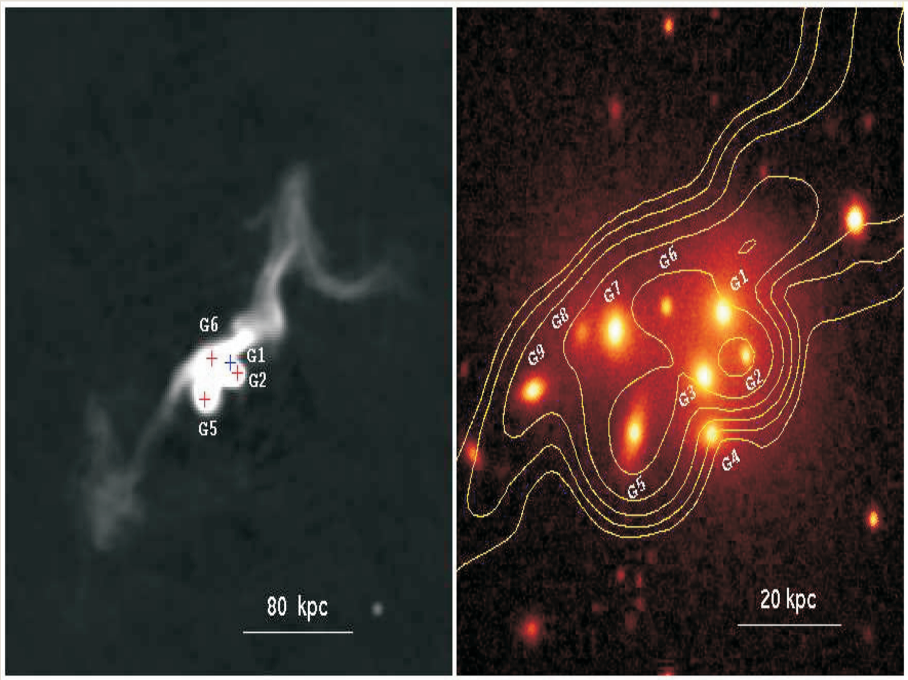


Figure 21: Left: GMRT 610 MHz radio image of radio source 4C 36.06 (at 5 arcsec resolution) with some optical galaxy positions marked which could be the host to the radio structure (which one it is not yet clear). Right: Optical SDSS image of the 9 galaxies (G1 to G9) in the 'Zwicky's Nonet' system with GMRT 610 MHz radio contours overlaid.

optical bands. The variations in the X-ray and UV/optical bands are strongly correlated. The reverberation mapping analysis using the JAVALIN tool showed that the variation in the UV/optical bands lag behind the variations in the X-ray band by $\sim 2-10$ days. These lag measurements strongly suggest that the optical/UV variations are mainly caused by variations in the X-rays, and the origin of the most of the optical/UV emission is X-ray reprocessing. The observed lags are found to vary as $\sim$ wavelength$^{1.3}$, consistent with the prediction for X-ray reprocessing in a standard accretion disc. However, the predicted lags for a standard accretion disc with X-ray reprocessing are shorter than the observed lags. These observations imply that the accretion disc in Fairall 9 is larger than that predicted by the standard disc model.

The origin of the soft x-ray excess emission

Labani Mallick and **Gulab C. Dewangan** have performed detailed study of their 2016 XMM-Newton observation of the narrow-line Seyfert 1 galaxy PG 1404 + 226, which showed a large-amplitude, rapid X-ray variability by a factor of about 8 in 11ksec. They used this variability event to investigate the origin of the soft X-ray excess emission and the connection between the disk, hot corona and the soft excess emitting region through UV/X-ray cross-correlation, time-resolved spectroscopy and root mean square (rms) spectral modelling. The weakly variable UV emission appears to lead the strongly variable X-ray emission by 33 ksec. Such a UV lead is consistent with the crossing time between the accretion disk and the hot corona and the time required for thermal Comptonization giving rise to the X-ray power-law emission. The strong soft X-ray excess below 1keV seen in the mean X-ray spectrum as well as in the time-resolved spectra is well described by both the intrinsic disk Comptonization and the blurred reflection models. The soft excess emission is found to vary together with the power-law component. The X-ray fractional rms spectrum showed an increase in variability with energy, which can be described only in the framework of blurred reflection model, in which both the intrinsic continuum and the reflected emission are highly variable in normalization only and are perfectly coupled with each other. These results suggest that accretion disk provides the seed photons for thermal Comptonization giving rise to the X-ray power-law component, which in turn illuminates the innermost accretion disk and gives rise to the soft X-ray excess emission.

Rapid variability of spectral parameters

Pramod Pawar, **Gulab C. Dewangan**, M. K. Patil, **Ranjeev Misra** and S. K. Jogadand have performed time resolved spectroscopy of two narrow-line Seyfert 1 galaxies 1H0707-495 and IRAS 13224-3809 using long XMM-Newton observations. These are strongly variable narrow line Seyfert 1 galaxies and show broad features around 1 keV that has been interpreted as relativistically broad Fe L lines. Such features are not clearly observed in other AGN despite sometimes having high iron abundance required by the best fitted blurred reflection models. Given the importance of these lines, they have explored the possibility if rapid variability of spectral parameters may introduce broad bumps/dips artificially in the time averaged spectrum, which may then be mistaken as broadened lines. They tested this hypothesis by performing time resolved spectroscopy using long ($> 100ks$) XMM-Newton observations and by dividing it into segments with typical exposure of a few ksec. They extracted spectra from each such segment and modelled using a two component phenomenological model, consisting of a power law to represent hard component and a black body to represent the soft emission. As expected, both the sources showed variations in the spectral parameters. Using these variation trends, the authors have simulated model spectra for each segment and then co-added to get a combined simulated spectrum. In the simulated spectra, no broad features below 1 keV, and in particular no deviation near 0.9 keV as seen in the real average spectra were seen. This implies that the broad Fe L line that is seen in the spectra of these sources is not an artefact of the variation of spectral components and hence providing evidence that the line is indeed genuine.

Broad-band spectral study of the Atoll source

Broad relativistic iron lines from neutron star X-ray binaries are important probes of the inner accretion disc. The X-ray reflection features can be weakened due to strong magnetic fields or very low iron abundances such as in X-ray binaries with low mass, first generation stars as companions. Aditya S. Mondal, **Gulab C. Dewangan, Mayukh Pahari, Ranjeev Misra, Ajit K. Kembhavi** and B. Raychaudhuri have investigated the reality of the broad iron line detected earlier from the neutron-star low-mass X-ray binary 4U 1820-30 with a degenerate helium dwarf companion. They have performed a comprehensive, systematic broad-band spectral study of the Atoll source using Suzaku and simultaneous NuSTAR and Swift observations. They used different continuum models involving accretion disc emission, thermal black body and thermal Comptonization of either disc or black body photons. The Suzaku data showed positive and negative residuals in the region of Fe K band. These features are well described by two absorption edges at 7.67 ± 0.14 keV and 6.93 ± 0.07 keV or partial covering photoionized absorption or by blurred reflection. Though, the simultaneous Swift and NuSTAR data did not clearly reveal the emission or absorption features, the data were found to be consistent with the presence of either absorption or emission features. Thus, the absorption based models provided an alternative to the broad iron line or reflection model. The absorption features may arise in winds from the inner accretion disc. The broad-band spectra were found to disfavour continuum models, in which the black body emission from the neutron-star surface provides the seed photons for thermal Comptonization. These results suggested emission from a thin accretion disc with an inner temperature of about 1 keV, Comptonization of disc photons in a boundary layer most likely covering a large fraction of the neutron-star surface and the innermost parts of the accretion disc, and black body emission (kTbb σ 2 keV) from the polar regions.

Reflected emission from accretion disk

Aditya S. Mondal, **Mayukh Pahari, Gulab C. Dewangan, Ranjeev Misra** and B. Raychaudhuri have studied two simultaneous NuSTAR and SWIFT observations of the Atoll type neutron star (NS) X-ray binary 4U 1728-34 observed on 1 and 3 October 2013. They have found that the first and the second observations belong to the island state and the lower banana state respectively. During island state, four type-I X-ray bursts are observed within 60 ks exposure. From the time-resolved spectral analysis of each burst with NuSTAR, the black body temperature kT_{bb} are found to vary between 1.3 and 3.0 keV and the blackbody radii varied between 3.5 and 7.4 km for an assumed distance of 5 kpc. The persistent, joint energy spectra from SWIFT and NuSTAR for both observations in the energy band 1 - 79 keV are well described with thermal emission from the NS surface ($kTbb \simeq 1 - 2.5\ keV$), Comptonized emission of thermal seed photons from the hot boundary layer/corona and the strong reflection component from the accretion disc. The authors have detected a broad Iron line in the 5 - 8 keV band and reflection hump in the 15 - 30 keV band and modelled as the reflected emission from the accretion disk, and have estimated the magnetic field to be $\sim$ 4e8 Gauss.

Optical and X-ray Variabilities

- During the last decade, simultaneous optical/X-ray variabilities studies in X-ray binaries became immensely important to understand the accretion and radiation mechanism in these system at different spectral states. **Mayukh Pahari** and collaborators (Poshak Gandhi, Phil A. Charles, Diego Altamirano and Marissa Kotze) have performed simultaneous optical (SALT) and X-ray (Swift and INTEGRAL) observations of GS 1354-64/BW Cir during the 2015 hard state outburst. During the rising phase, optical/X-ray time series show a strong anti-correlation with X-ray photons lagging optical. Optical and X-ray power spectra show quasi-periodic oscillations at a frequency of $\sim$18 mHz with a confidence level of at least 99%. Simultaneous fitting of Swift/XRT and INTEGRAL spectra in the range 0.5-1000 keV shows non-thermal, power-law dominated ($>$ 90%) spectra with a hard power-law index of 1.48 $\pm$ 0.03, inner disc temperature of 0.12 $\pm$ 0.01 keV and inner disc radius of $\sim$3000 km. All evidences are consistent with cyclo-synchrotron radiation in a non-thermal, hot electron cloud extending to $\sim$100 Schwarzschild radii being a major physical process for the origin of optical photons. At outburst peak about one month later, when the X-ray flux rises and the optical drops, the apparent features in the optical/X-ray correlation vanish and the optical auto correlation widens. Although $\sim$ 0.19 Hz QPO is observed from the X-ray power spectra, the optical variability is dominated by the broadband noise, and the inner disc temperature increases. These results support a change in the dominant optical emission source between outburst rise and peak, consistent with a weakening of hot flow as the disc moves in.

Joint energy spectral fitting

- **Mayukh Pahari**, I. M. McHardy, **Gulab C. Dewangan**, **Ranjeev Misra** and **Labani Mallick** perform the *NuSTAR* and *Swift*/XRT joint energy spectral fitting of simultaneous observations from the broad-line Seyfert 1.5 galaxy NGC 5273. When fitted with the combination of an exponential cut-off power-law and a reflection model, a high energy cut-off is detected at 143^{+96}_{-40} keV with 2σ significance. Existence of such cut-off is also consistent with the observed Comptonizing electron temperature when fitted with a Comptonization model independently. Additional evidences for cut-off come from the non-detection of the source by *INTEGRAL*/ISGRI in 30-200 keV with 3σ limit and a significant drop in the fractional rms variability at higher energies ($>$ 20 keV). When the hard band count rate (6-20 keV) is plotted against the soft band count rate (3-6 keV), a hard offset is observed. The results indicate that the cut-off energy may not correlate with the coronal X-ray luminosity in a simple manner. Similarities in parameters that describe coronal properties indicate that the coronal structure of NGC 5273 may be similar to that of the broad-line radio galaxy 3C 390.3 and another galaxy MCG-5-23-16, where the coronal plasma is dominated by electrons, rather than electron-positron pairs. Therefore, the coronal cooling is equally efficient to the heating mechanism keeping the cut-off energy at low even at the low accretion rate.

Studies using the data of Large Area X-ray Proportional Counter on-board AstroSat

- Extensive analysis were carried out using the performance verification (PV) and guaranteed time (GT) data of Large Area X-ray Proportional Counter (LAXPC) on-board *AstroSat*, India's first multi-wavelength astronomical satellite. **Mayukh Pahari**, H. M. Antia, J.S. Yadav, **Ranjeev Misra** and other LAXPC team members have used data from galactic X-ray binaries like Cyg X-1, Cyg X-3 and GRS 1915+105 to perform the spectro-timing analysis. They have found energy-dependent variability of timing properties from GRS 1915+105 and Cyg X-1, while they observed milli-hertz quasi-periodic oscillations from Cyg X-3. For the first time, the energy-dependent time lag is computed at energies higher than 20 keV and dramatic variability is seen from GRS 1915+105. The flux dependent behaviour of the power density spectra is studied and a complex pattern is observed.

Compact Objects

White dwarfs

White Dwarfs are a type of compact final remnants produced at the end of the evolution of stars up to about 10 times the mass of the sun. Standard theory suggests that white dwarfs cannot be heavier than 1.4 solar mass, known as the Chandrasekhar mass limit. Recently, it has been suggested that in the presence of ultra strong magnetic fields the white dwarf mass limit may exceed this value. **Prasanta Bera**, and **Dipankar Bhattacharya** have investigated the stability of supermassive, magnetically supported white dwarfs and found that they suffer from strong instabilities that limit their lifetime to only a few seconds. Such objects are, therefore, not expected to be found among the cosmic white dwarf population.

Neutron stars

Neutron stars are highly compact and massive stellar remnants composed primarily of neutrons. They can spin very rapidly, up to a thousand times a second. Any mass distribution asymmetry on these fast spinning neutron stars would be a source of periodic gravitational wave radiation. Strongly magnetised neutron stars in binary systems can accrete matter from their companion and accumulate the accreted matter on their magnetic poles. Sushan Konar, D. Mukherjee, **Dipankar Bhattacharya**, P. Sarkar have estimated that the gravitational waves emitted due to such magnetically confined mountains on fast spinning neutron stars may be strong enough to be detected by the next generation gravitational wave observatories.

SALT observations

A unique X-ray source, 4U 1626-67, was studied at optical wavelengths with the Southern African Large Telescope (SALT) by **Dipankar Bhattacharya,** Vijay Mohan, Gayathri Raman, and Biswajit Paul. In this system, a neutron star is accreting matter from a very low mass binary companion. The observed X-rays are pulsed at 7.67 sec, which is the rotation period of the neutron star. The optical light from the system is generated by reprocessing in the material around the neutron star and exhibits the same pulse period. However, the phase of the periodic optical emission seen in this observations exhibits a large wander during flaring activity. This reveals, for the first time, strong matter outflow from the system at speeds of several thousand kms^{-1}.

Stars, Interstellar Medium and Planetary Studies

Optical spectroscopy and photometry of main-belt Aasteroids with a high orbital inclination

Observations and detailed study of Asteroid spectra and their classfications helps in understanding the solar system formation. The size distribution of high orbital inclination asteroids provides us with information regarding the process of planetesimal collision under different conditions from those of low orbital inclination planetesimals. **Ranjan Gupta** et al. have carried out low-resolution optical spectroscopy of MBAs using the Wide Field Grism Spectrograph 2 (WFGS2) mounted on the University of Hawaii (UH) 2.2 m telescope, and also employed the IUCAA Faint Object Spectrograph and Camera (IFOSC) mounted on the 2 m telescope at the IUCAA Girawali Observatory (IGO), India.

The main conclusions of this study are:

1. For the asteroids with a semi-major axis of between 2.1 AU and 3.3 AU, and with a high orbital inclination, the fraction of D-type asteroids was higher than that of the asteroids with the same range of semi-major axis and with a low orbital inclination.

2. The fractions of C- and S-type asteroids are comparable between those asteroids with a semi-major axis of between 2.1 AU and 2.5 AU and a high orbital inclination and asteroids with a low orbital inclination.

3. An abundant population of D-type main-belt asteroids with a high orbital inclination indicates that a fraction of the high orbital inclination asteroids were formed near Jupiter, and then migrated inward obtaining a highly-inclined orbit.

Unveiling Vela : Time variability of interstellar lines in the direction of the Vela supernova remnant

II. Na D and Ca II

Vela supernova remnant (SNR) is the closest relic of a stellar explosion to earth, located at a distance of 287 ± 19 pc, as inferred from the VLBI parallax of its pulsar, and represents a supernova explosion that occurred 11,000 years ago. Observational studies of interstellar lines present in the spectra of stars in the direction of Vela SNR provide information about the interaction of the remnant with local interstellar medium (ISM). Such studies predominantly concentrated on profiles of CaII K and NaI D lines superimposed on stellar spectra. In a survey conducted during 2011-2012 of interstellar NaI D line profiles in the direction of the Vela supernova remnant, a few lines of sight showed dramatic changes in low velocity absorption components with respect to profiles from 1993-1994. High spectral resolution observations of CaII K lines were obtained with the Vainu Bappu 2.3 m telescope and the Southern African Large Telescope (SALT) towards the three stars (HD 63578, HD 68217 and HD 76161) along with simultaneous observations of NaI D lines. These new spectra confirm that the NaI D interstellar absorption weakened drastically between 1993-1994 and 2011-2012, but show for the first time that the Ca II K line is unchanged between 1993-1994 and 2015. This remarkable contrast between the behaviour of Na D and Ca II K line absorption lines is a puzzle concerning gas, presumably affected by the outflow from the SNR and the wind from γ^2 Velorum.

The Figure 22 shows the changes in NaI D lines over the period from 1993 to 2011.

One of the main conclusions of this study is the remarkable changes in Na D lines unaccompanied by Ca K line changes, which occur on sight lines to SNR or through a region crossed by a vigorous stellar wind and have not been seen via sight lines through the ambient diffuse stellar medium.

Automated classification of LAMOST DR3 FGK spectra

LAMOST is a major project, where several million spectra are being taken by a reflecting Schmidt telescope placed at Xinglong Station, Hebei Province, China. We have restricted to a limited data base of

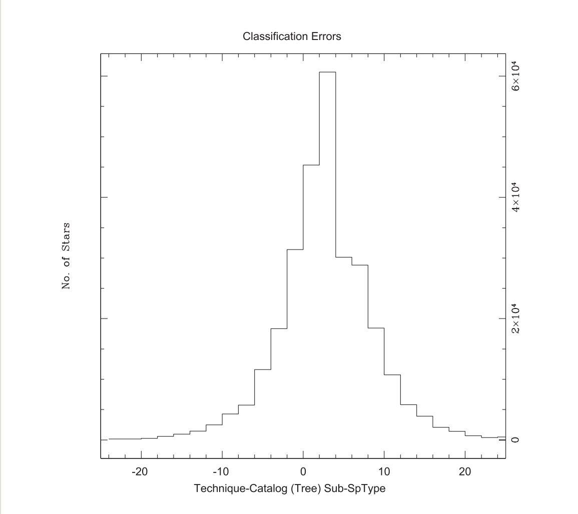


Figure 23: Classification histogram for Tree classfier.

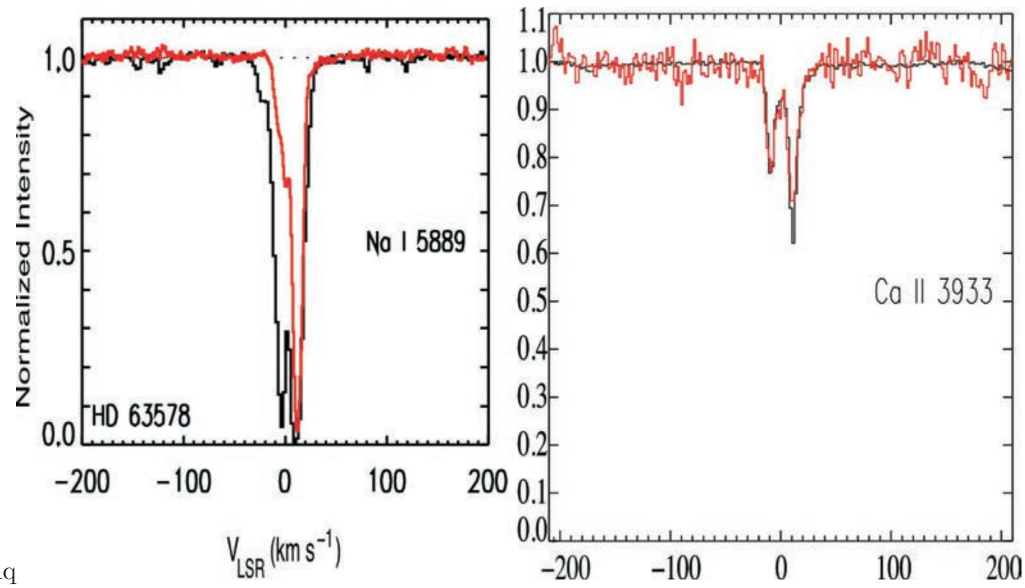
286,283 FGK spectra from the LAMOST DR3 release. Automated classification tools Artificial Neural Network (ANN), Multi-Level Decision Tree, and Random Forest were employed on this large spectral data base using relevent Miles spectral library as a training set.

Figures 23 and 24 **Ranjan Gupta** et al. show the classification histogram for the best classifier, i.e., Tree classifier and the corresponding 3D plot of classification errors. The best result on this preliminary classification excercise is 71.4% correct classificaton with a sub-spectral type error of 4.61. It may be noted that the LAMOST pipeline classes do not provide luminosity class information, whereas the ANN tools will provide this.

Solar Astrophysics

Loop top heating of post flare loops

Solar flares are the most energetic phenomena observed on the surface of the Sun and are the most important solar activity for space weather and geospace climate. There have been a lot of improvements on the understanding of such phenomena, many details are still unclear. One of the details is to what creates localised bright emission at the



omq

Figure 22: Left: Profile of NaI D2 in HD 63578 obtained in 2011 (red line) shown superposed on the profile of NaI D2 observed in 1993 by Cha and Sembach (2000)(black line). The blue-shifted absorption components in the 1993 spectrum (black line) are absent in the 2011 spectrum. Right: CaII K profiles of HD 63578 obtained with SALT in 2015 (red line) overplotted on profile obtained by Cha and Sembach (2000) in 1993.

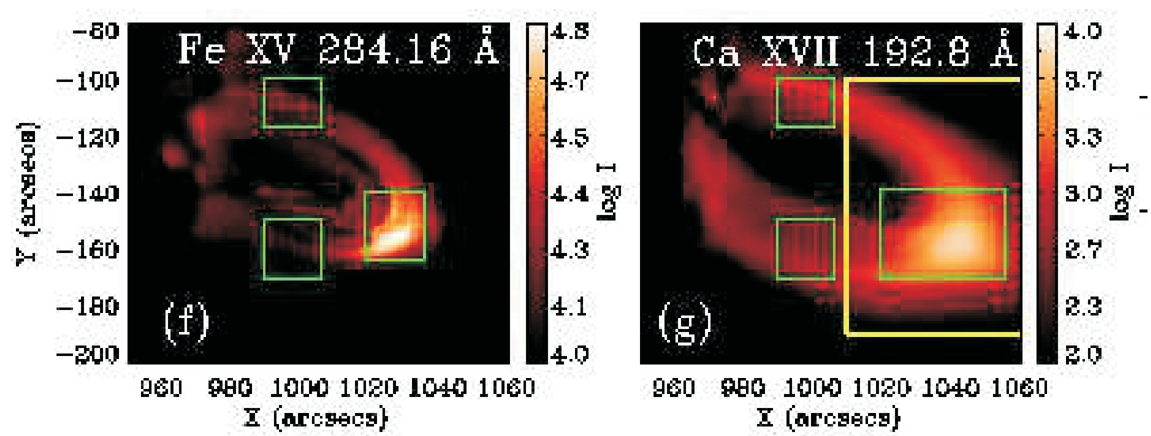


Figure 25: A system of post-flare loops observed in two different spectral lines namely Fe XV (panel f) and Ca XVII (panel g) from the Extreme-Ultraviolet Imaging Spectrometer on board the Hinode satellite. These two lines represent solar plasma at 2.5 million and 5.6 million respectively. The bright tip of loops are evident in both the images.

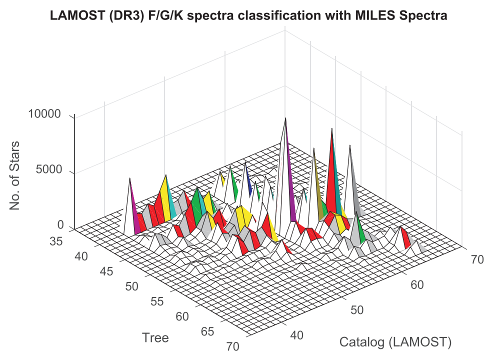


Figure 24: A 3D plot showing the classification errors with the Tree classifier.

top of the post flare loops, (see Figure 25). Using a simple one dimensional hydrodynamic simulation, **Durgesh Tripathi** and **Avyarthana Ghosh,** along with Sharma and Isobe have shown that these localized brightenings can be explained by the collision of the chromospheric evaporation that occurs as a result of the magnetic reconnection in the corona and deposits heats at the footpoints of the loops. The study also provides an explanation to the fact that why there are no post eruption arcades following some of the coronal mass ejections.

Active region fan loops

Heating of the solar atmosphere, in particular, the corona is one of the most stubborn problems in the field of astrophysics. Active regions are the best demonstrations of the pronounced heating of the upper solar atmosphere, and they are comprised of different kind of loops. These loops are of different length scales and they evolve at different time scales. The most complex of these are the fan loops, which are formed at $0.8 - 1.0\ MK$. These are identified as one of the most complex and longest-living loops structures. **Avyarthana Ghosh, Durgesh Tripathi** and **Girjesh Gupt** along with other colleagues have combined multi-spacecraft observations to provide most comprehensive multi-wavelength study of physical properties of these fan loops. The study reveals that the measured physical properties of fan loops are best explained by low frequency nanoflares, where the time delay between two successive heating events is larger than the cooling time. The Doppler measurements show that the plasma is all time cooling and draining. The question that still remains is to identify the process that puts the plasma in the coronal. This study suggests that the process behind this could be chromospheric evaporation. However, there are no such observations in quiescent coronal loops. The fan loops studied here represent a classic example of the direct coupling of the different layers of the atmosphere. Figure 25, right panel, displays observations of a set of fan-like structure (called fan loops), that is rooted in the umbra of a sunspot as seen in the left panel.

Active region jets

Active region jets (AR jets) are the impulsive, dynamic transient events, and have been observed to occur at the edge of active regions, and mostly associated with a west side of leading sunspot region (see Figure 27). The signatures of these events have been observed in number of wavelength channels such as H, EUV/UV and X-rays. These transients are capable of transferring mass and energy from one layer to another in the solar atmosphere, and also are considered to be an important source of feeding mass and energy to the solar wind. **Durgesh Tripathi** along with colleagues has performed comprehensive multi-wavelength study of 20 EUV AR jets, and reported on the multi-temperature component of the plasma and their relationship with radio type-III burst.

Damping of Alfven waves in the solar corona

Direct identification of Alfvén waves is not so easy in the solar corona, however, their contribution can be quantified using non-thermal broadening of spectral line profiles. **Girjesh Gupta** has utilised high resolution spatial and spectral data from the EIS instrument to estimate the Alfvén wave energy flux and their damping with height along the solar active region. A significant decrease in wave energy fluxes with height was detected in the form of decreasing line width, and hence provide evidence of Alfvn wave damping (see Figure 28).

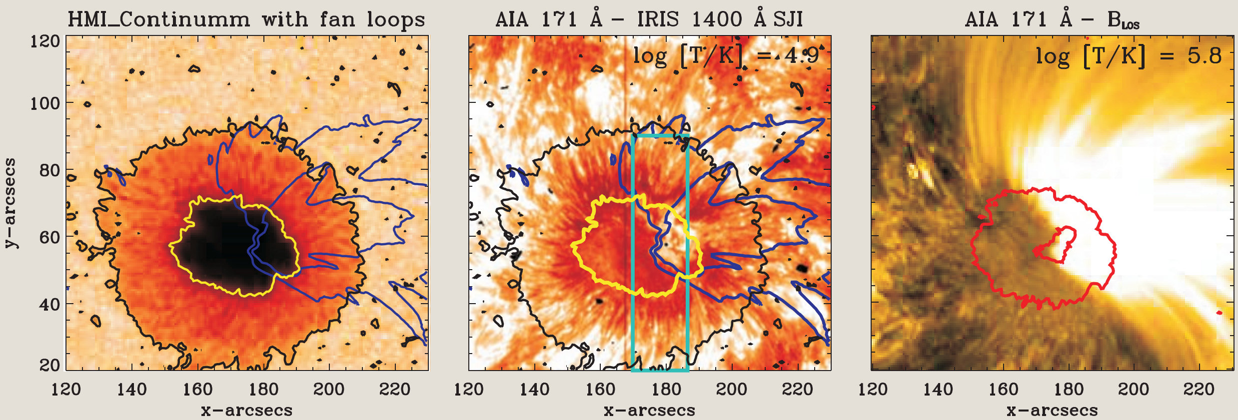


Figure 26: Observations of a system of fan loops that is rooted deep inside an umbra of a sunspot. The left panel shows the sunspot observed in photosphere with SDO/HMI over-plotted with contours demarcating umbra (yellow), penumbra (black) and coronal fan loops (blue). The middle panel shows the same region as left panel, but in chromosphere using IRIS over-plotted with same contours as in the left panel. The white box shows the regions, which are scanned with IRIS.

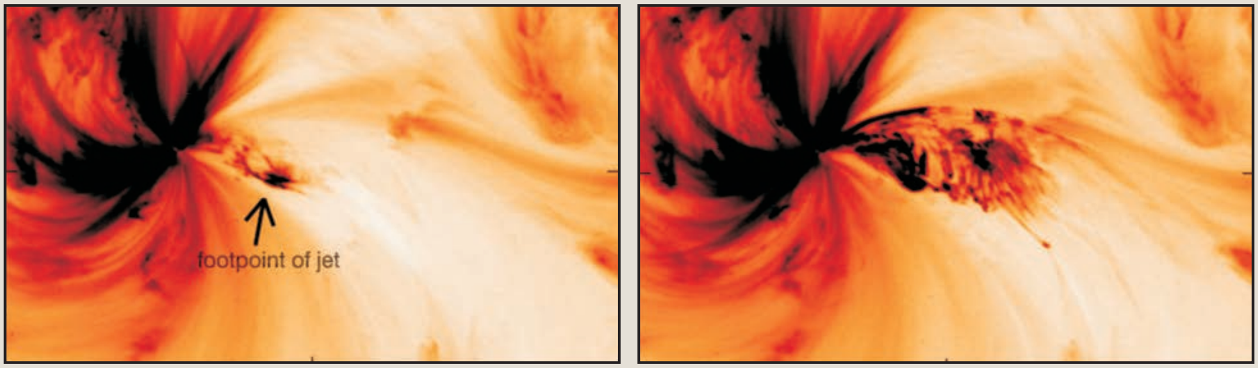


Figure 27: An active region jet observed at two different times by the Atmospheric Imaging Assembly (AIA) on boardthe Solar Dynamics Observatory (SDO) using the 193 A channel.

The Solar Ultraviolet Imaging Telescope

The Solar Ultraviolet Imaging Telescope (SUIT) on board ISRO's Aditya-L1 mission will for the first time provide full disk observations of the Sun in the wavelength range of 200 - 400 nm. This mission is already approved and is scheduled to be launched by 2020. SUIT will observe the solar atmosphere, from the lower photosphere to the upper chromosphere, using 11 different filters that will be imaging the different layers simultaneously. The instrument has gone through preliminary design review in December 2016 and January 2017. Figure 29 displays the current model of the SUIT payload.

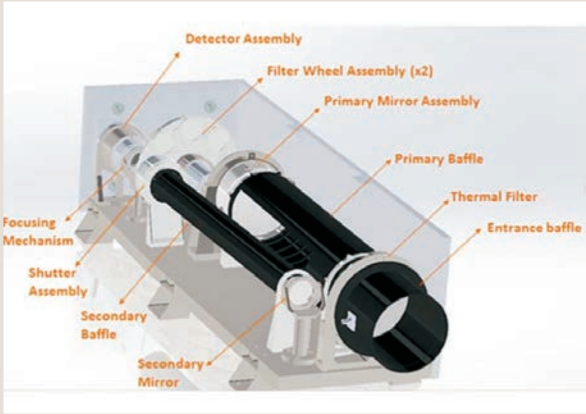


Figure 29: The current design of the Solar Ultraviolet Imaging Telescope (SUIT) on board Aditya-L1 mission.

Instrumentation

Devasthal optical telescope integral field spectrograph

Devasthal Optical Telescope Integral Field Spectrograph (DOTIFS) is a new multi-object integral field spectrograph being built by IUCAA, for the 3.6 m Devasthal Optical Telescope (DOT), which has been constructed by the Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital. DOTIFS is mainly designed to study the physics and kinematics of ionized gas, star formation and H II regions in the nearby galaxies. This is a novel

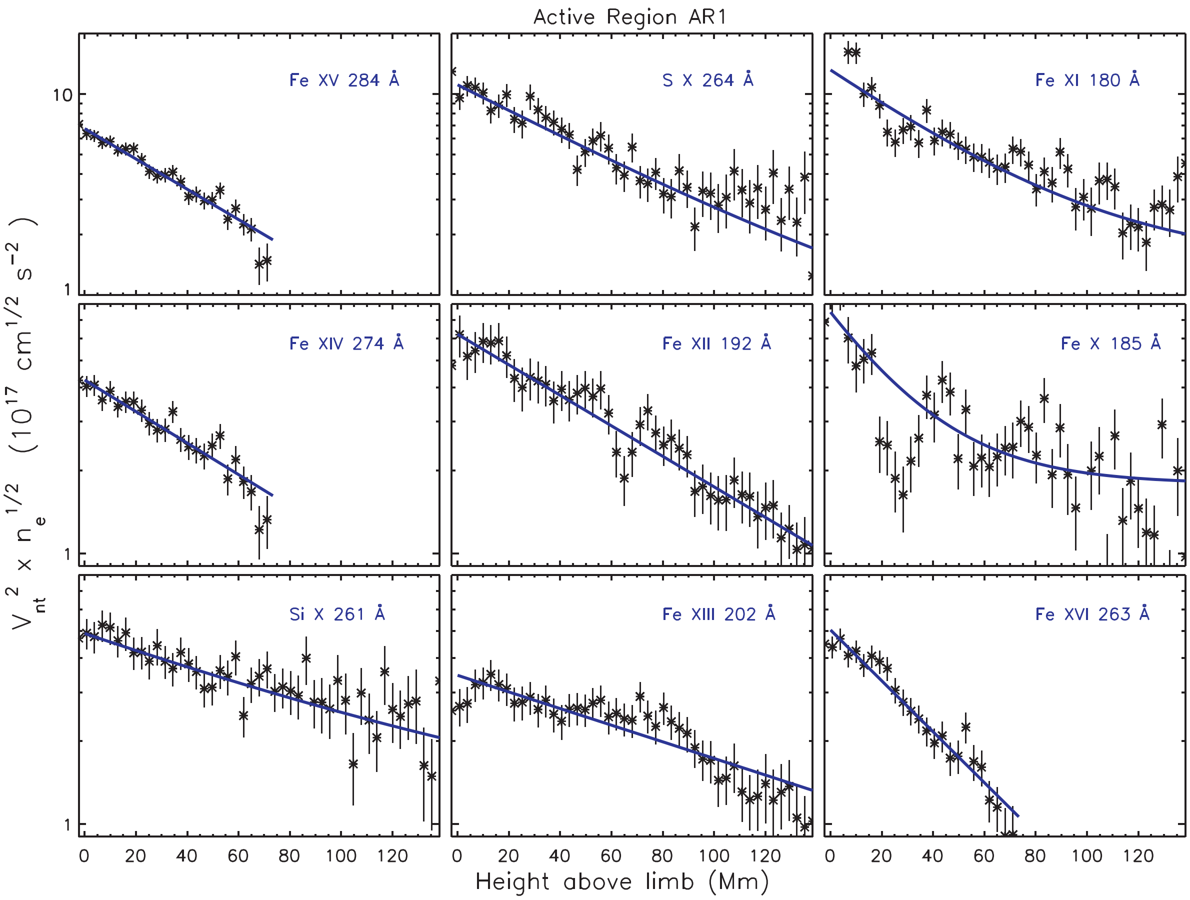


Figure 28: Variation of Alfvén wave energy flux with height along active region obtained from various spectral lines as labeled. Over-plotted continuous lines are fitted exponential decay profile to obtain wave damping lengths from various spectral lines formed at range of temperatures. Calculated Alfvén wave energy fluxes are of similar order of magnitude, which is required to maintain the active region corona.

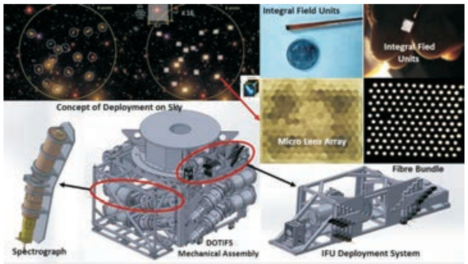


Figure 30: Different Aspects of DOTIFS

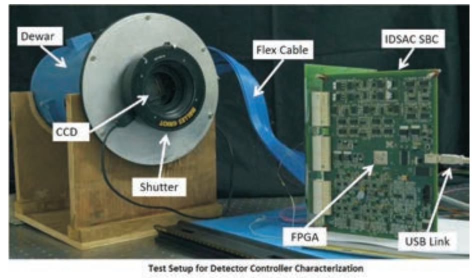


Figure 31: Test setup for IDSAC Characterization

instrument in terms of multi-IFUs, built in deployment system, and high throughput. A magnifier at the Cassegrain side port of the telescope feeds sixteen integral field units (IFUs) which can be deployed over an 8 diameter focal plane by x-y actuators. An intelligent deployment algorithm has been developed to allow optimized reconfiguration and to avoid any collision between IFUs. The instrument is at the phase of fabrication and is scheduled to be commissioned in early 2018.

Although IUCAA is responsible for developing the entire instrument, **Sabyasachi Chattopadhyay** has specifically worked on (a) development of IFUs, (b) IFU deployment algorithm, and (c) development of detector control system. IFUs are the heart of the instrument, which carries light from sky to spectrograph via bundle of fibres. Until now, we have developed a prototype IFU with σ 10 μm positioning accuracy of fibres using the unique technique of photo-lithography. The deployment system has been developed in such way that not only it is intelligent enough to avoid collision but also it moves the IFUs within detector readout time (σ 40s) to avoid overhead. Detailed work has been carried out to implement and understand the use of Digital Correlated Double Sampling (DCDS) in detector controller. Analytical model supported by simulation results shows that prediction of read noise is within 10% of laboratory measurements.

Wide area linear optical polarimeter

Linear optical polarisation up to a few percent levels is observed in all stars due to dichroic (polarisation state dependent) scattering and absorption of star light in optical wavelengths by inter-stellar non-spherical dust grains aligned along the local magnetic field. Through previous studies, it has been well established that all stars behind a dust cloud have similar degrees and angles of linear polarisation, with the former indicating dust content and the latter aligned along the local magnetic field direction. So if there are two dust clouds in a line of sight, all stars behind the first dust cloud will have similar polarisations (degree and angle), and stars behind the second dust cloud will have polarisations similar to each other but different from that of stars behind the first cloud. Using the above concept, 3-D dust cloud and magnetic field tomography can be carried out for the Milky Way if accurate polarisation measurements can be made for a large number of stars in a patch of sky.

To pursue this objective, Wide Area Linear Optical Polarimeter (WALOP) instruments are being developed. WALOP is a wide field (30 $arcmin \times 30$ $arcmin$) optical polarimeter currently being designed and developed by **A. N. Ramaprakash** and **Siddharth Maharana** for two telescopes(1.3 m Skinakas Observatory, Greece and 1 m Sutherland Telescope, South Africa) to carry out high precision (0.1%) linear polarisation measurement survey of stars in Milky Way. The project is in collaboration with IUCAA, Caltech (USA), University of Crete (Greece) and SAAO (South Africa).

WALOP will employ novel optical prisms to measure polarisation. **Siddharth Maharana** has carried out tests on these prisms in IUCAA instrumentation laboratory and found that their performance met the required levels of accuracy.

CZTI deector aboard AstroSat

The CZTI detector aboard AstroSat has been regularly detecting Cosmic Gamma Ray Bursts (GRBs). GRBs are powerful flashes of gamma radiation that signal the birth of black holes in the universe. The CZTI Payload Operations Centre at IUCAA routinely examines the data for such flashes and detections are reported immediately as GRB Coordination Network (GCN) circulars. Detailed analysis of the properties of the brightest GRBs detected by the CZTI also reveals a significant degree of polarization in the gamma ray signal. **Dipankar Bhattacharya, Varun Bhalerao, Vidushi Sharma, Ajay Vibhute,** Santosh Vadawale, A.R. Rao and the CZTI team are working on this project.

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10. Xian O. Camanho, **Naresh Dadhich** and Alfred Molina (2016) *(Not so) Pure Lovelock Kasner metrics,* Procds. 14th Marcel Grossman Meeting on General Relativity, Eds. Massimo Bianchi, Robert T. Jantzen and Remo Ruffini, World Scoentific, Singapore.

11. **Naresh Dadhich** (2017) *Understanding General Relativity after 100 Years: A Matter of Perspective, in Gravity and the Quantum,* Eds. Jasjit S. Bagla and Sunu Engineer, Springer, 73.

12. Kulinder Pal Singh, Godon Stewart, Sunil Chandra, Kallol Mukherjee, ... , **Gulab Dewangan,** et al. (2016) *In-orbit performance of SXT aboard AstroSat*, Procds. Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, **9905,** 99051E.

13. **Avyarthana Ghosh**, **A.N. Ramaprakash, Durgesh Tripathi,** et al. (2016) *The Solar Ultraviolet Imaging Telescope onboard Aditya-L1,* Procds. Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series **9905,** 990503.

14. L.B. Newburgh, K. Bandura, M.A. Bucher, T.-C. Chang, ... , **Neeraj Gupta,** et al. (2016*) HIRAX: A probe of dark energy and radio transients,* Procds. Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, **9906E,** 5XN.

15. Robert Hanisch, Michael Wise, Masatoshi Ohishi, Heinz Andernach, ... , **Ajit Kembhavi,** et al. (2016) *Division B Commission 5: Documentation and astronomical data,* IAUTA, **29,** 84.

16. **Jayant V. Narlikar** (2016) *What should we expect from a model of the Universe?,* La Nuova Critica, Rivista Di Scienze Dell'uomo E Di Filosofia Delle Scienze, Nuova Serie, I - II, 9.

17. **Jayant V. Narlikar** (2017) *Some conceptual problems in cosmology,* Procds. National Conference on Current Issues in Cosmology, Astrophysics and High Energy Physics, Ed. Umananda D. Goswami, **1,** 3.

18. Sultanah Al Otaibi, Peter Tino and **Somak Raychaudhury** (2016) *Probabilistic modelling for delay estimation in gravitational lensed photon streams,* Procds. Intl. Conf. Intell. Data Engg. Auto. Learn. (IDEAL), Yangzhou, China, Eds. Hujun Yin, et al., 552, Springer Verlag.

19. Dimitri A. Gadotti, **Sonali Sachdeva, Kanak Saha** and Harinder Pal Singh (2017) *The observed peripheral growth of disc galaxies from z ~ a,* Procds. IAU Symp., **321,** 324.

20. S.K. Goyal, **Kandaswamy Subramanian,** et al. (2016) *Multi-directional measurements of high energy particles from the Sun-Earth L1 point with STEPS*, Procds. Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series **9905,** 99054N.

21. **Durgesh Tripathi** (2016) *The Aditya - L1 mission of the Indian Space Research Organization,* Procds. 41st COSPAR Scientific Assembly, Istanbul, Turkey, D 2.2-3-16.

22. I. Cairns, D. Oberoi, J. Morgan, ... , **Durgesh Tripathi,** et al. (2017) *MWA observations of solar radio bursts and the quiet sun,* MWA Proposal 2017A - 06..

(c) BOOKS AUTHORED

Jayant V. Narlikar (2016) *My Tale of Four Cities,* National Book Trust, India, New Delhi.

Jayant V. Narlikar (2017) *Ganit Ani Vidnyan: Yugayuganchi Jugalbandi* (in Marathi) (Mathematics and Science: Their Coordinated Progress), Rajhans Prakashan, Pune.

(d) POPULAR ARTICLES

Jayant V. Narlikar

How science demolishes ego, The Asian Age, April 13, 2016.

Raja Jai Singh and his zij, The Asian Age, May 5, 2016.

When some are more equal than others ... , The Asian Age, June 3, 2016.

Are we serious about clean India?, The Asian Age, July 26, 2016.

A challenge to 'smart cities', The Asian Age, August 20, 2016.

Difficult problems, simple solutions, The Asian Age, September 15, 2016.

Our strange universe, The Asian Age, October 21, 2016.

Discoveries take science by surprise, The Asian Age, November 29, 2016.

Here's why science declined in India, The Asian Age, December 14, 2016.

Wonderful world of mathematics, The Asian Age, January 28, 2017.

How a good teacher operates ... , The Asian Age, February 22, 2017.

How many cheers for democracy?, The Asian Age, March 10, 2017.

Gravitational waves: Their searches and discovery, Pragaami Tarang, VII, 1, 2016.

Rashtriya ekata, vidnyan aur hindi ka tribhuj (in Hindi) (National integration, Science and Hindi: A triangular interaction), Rashtreeya ekta kee kadee: Hindi Bhasha aur Sahitya, 32, 2016.

Vaidnyanik drustikon (in Hindi) (Scientific outlook), Scientific Outlook, 1, 2016.

Einstein barobar photo! (in Marathi) (A photograph with Einstein!), Saptarang, Sakal, April 3, 2016.

Khagol vidnyan ka shikave? (in Marathi) (Why study astronomy?), Vidnyanvahini, 48, 2016.

Vaidnyanikanche gun-dosh (in Marathi) (Scientists with their pluses and minuses), Saptarang, Sakal, May 1, 2016.

Swachatechya magavar ...! (in Marathi) (On the track of cleanliness), Saptarang, Sakal, June 5, 2016.

Sagale saman? navhe; kahijan adhik saman! (in Marathi) (All are equal, but some are more equal than others), Saptarang, Sakal, July 3, 2016.

Katkasaricha vidnyan (in Marathi) (Cut cost science), Saptarang, Sakal, August 7, 2016.

Aapla shahar smart kasa honar? (in Marathi) (How will our city becomes smart?), Saptarang, Sakal, September 4, 2016.

Atyant hushar ganiti: von Neumann (in Marathi) (von Neumann: A brilliant mathematician), Saptarang, Sakal, October 2, 2016.

Aani surya hasla! (in Marathi) (And the Sun laughed!), Chhatra Prabodhan, Diwali Issue, 23, 2016.

Aamche tatya (in Marathi) (My father), Jadan Ghadan, November - December Issue, 11, 2016.

Shejaranyo firku naka ekade ... (in Marathi) (Neighbours do not come this way), Dharmabhaskar November - December, Diwali Issue, 21, 2016.

Cambridgemadhale 'Proctor' aani tyanche 'Bulldog'! (in Marathi) (Proctor and his bulldogs in Cambridge), Saptarang, Sakal, November 6, 2016.

Vidnyanat prayogancha mahima (in Marathi) (The importance of experiments in science), Saptarang, Sakal, December 4, 2016.

Sir salamat magar helmet ki mijas ... (in Marathi) (Respect the helmet to save your head), Loksatta, January 29, 2017.

Sanskrit bhashetale vinod: Kahi udaharane (in Marathi) (Some examples of humour in Sanskrit), Dharmabhaskar, February Issue, 13, 2017.

Abhayaranya (in Marathi) (Sanctuary: A science fiction story), *Safar Vidnyankathanchi,* 6, 2017.

(a) IUCAA-NCRA GRADUATE SCHOOL LECTURES

Dipankar Bhattacharya

Introduction to Astronomy and Astrophysics II (14 lectures) (October – December 2016).

Gulab C. Dewangan

Extragalactic Astronomy II (14 lectures) (March - May 2016), and Introduction to Astronomy and Astrophysics I (14 lectures) (August – September 2016).

Neeraj Gupta

Interstellar Medium (14 lectures) (March - May 2016).

Ranjeev Misra

Electrodynamics and Radiative Processes II (14 lectures) (October - December 2016).

Aseem Paranjape

Methods of Mathematical Physics I (21 lectures) (August -September 2016), and Extragalactic Astronomy - I (21 lectures) (January - February 2017, with Tirthankar Roy Choudhury, NCRA, Pune).

Somak Raychaudhury

Astronomical Techniques I (14 lectures) (January - February 2017).

Tarun Souradeep:

Methods of Mathematical Physics II (14 lectures) (October - December 2016).

(b) SAVITRIBAI PHULE PUNE UNIVERSITY M. Sc. (DEPARTMENTS OF PHYSICS AND SPACE SCIENCE) LECTURES

Ranjan Gupta

Laboratory Course (10 lectures), and related to Observational Astronomy (10 lectures) and night experiments.

Varun Sahni

Astronomy and Astrophysics II (Cosmology).

R. Srianand

Astronomy and Astrophysics II (Introduction to Astronomy).

Kandaswamy Subramanian

Astronomy and Astrophysics I (18 lectures).

(c) SUPERVISION OF Ph. D. THESES (DEGREES AWARDED)

Gulab C. Dewangan

Co-guide
Title: *X-ray Emission from Black Hole X-ray Binaries,*
Student: Shah Alam (Jamia Millia Islamia, New Delhi).

Co-guide
Title: *Correlation Between Optical and X-ray Varibility of Active Galactic Nuclei*,
Student: Pramod Pawar (S.R.T.M. University, Nanded).

Ranjeev Misra

Title: *Modelling Spectral Timing Behaviour of Compact Objects,*
Student: Nagendra Kumar (IUCAA).

T. Padmanabhan

Title: *Classical and Quantum Aspects of Gravity in Relation to the Emergent Paradigm,*
Student: Sumanta Chakraborty (IUCAA).

Tarun Souradeep

Title: *Seeking Physics Beyond the Isotropic Cosmological Model,*
Student: Suvodip Mukherjee (IUCAA).

R. Srianand

Title: *Intergalactic Medium and Cosmic Background Radiation,*
Student: Vikram Khire (IUCAA).

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

Dipankar Bhattacharya

Title: *Study of the Magnetic Fields of Neutron Stars through Cyclotron Resonance Scattering Features,*
Student: Suman Bala (IUCAA).

Title: *Strongly Magnetised Degenerate Stars,*
Student: Prasanta Bera (IUCAA).

Title: *Probing the Central Engine and Early Emission of Gamma Ray Bursts,*
Student: Vidushi Sharma (IUCAA).

Title: *Indirect Imaging in Astronomy,*
Student: Ajay Vibhute (Savitribai Phule Pune University).

Sukanta Bose

Title: *Improving the Detection Efficiency and Parameter Estimation of Neutron Star Binaries through Better Gravitational Waves Modelling,*
Student: Kabir Chakravarti (IUCAA).

Title: *Spacetime Mapping,*
Student: Sayak Datta (IUCAA).

Title: *Numerical Study of Wave Propagation in General Relativity,*
Student: Shalabh Sharma (IUCAA).

Title: *Strategies for Search of Electromagnetic Counterparts of Gravitational Waves Signals,*
Student: Javed Rana Sk. (IUCAA).

Gulab C. Dewangan

Title: *Energy-Dependent Variability of Active Galactic Nuclei,*
Student: Labani Mallick (IUCAA).

Title: *X-ray Spectral Variability of Active Galactic Nuclei,*
Student: Mainpal Rajan (IUCAA).

Co-guide
Title: *Radio-loud Active Galactic Nuclei,*
Student: Ritesh Ghosh (Visva-Bharati University, Santiniketan).

Co-guide
Title: *Broad Iron Lines from Neutron Star Low Mass X-ray Binary,*
Student: Aditya Sow Mondal (Visva-Bharati University, Santiniketan).

Sanjit Mitra

Title: *Sources of Gravitational Waves and Efficient Observation with Laser Interferometric Detectors,*
Student: Anirban Ain (IUCAA).

Title: *Efficient Methods for Detection of Gravitational Waves from Compact Binary Coalescences,*
Student: Bhooshan Gadre (IUCAA).

Title: *Characterization and Reduction of Noise in Gravitational Waves Detectors,*
Student: Nikhil Mukund (IUCAA).

Co-guide
Title: *Probing the Universe with Gravitational Waves Astronomy,*
Student: Abhishek Parida (Jamia Millia Islamia, New Delhi).

T. Padamanbhan

Co-guide
Title: *Facets of Gravity,*
Student: Rajeev Karthik (IUCAA).

Aseem Paranjape

Title: *Facets of Gravity,*
Student: Rajeev Karthik (IUCAA).

Title: *Analytical and Semi-Numerical Techniques for Next Generation Observations of LSS,*
Student: Niladri Paul (IUCAA).

A.N. Ramaprakash

Title: *Some Aspects of Design and Development of a Fibre-fed 2 D Spectrosgraph for the 3.6 m Devasthal Optical Telescope,*
Student: Sabyasachi Chattopadhyay (IUCAA).

Title: *Design and Development of Wide Field Optical Polarimeters (WALOP) for Dust Tomography,*
Student: Siddharth Maharana (IUCAA).

Somak Raychaudhury

Title: *The Evolution of Galaxies on the Cosmic Web,*
Student: Ruchika Seth (IUCAA).

Varun Sahni

Title: *The Emergent Scenario and Other Investigations in Relativistic Cosmology,*
Student: Satadru Bag (IUCAA).

Title: *Dark Matter, dark Energy and the early Universe,*
Student: Swagat Sourav Mishra (IUCAA).

Tarun Souradeep

Title: *Physics beyond Statistical Isotropy at Late Universe,*
Student: Debabrata Adak (IUCAA).

Title: *Precision Physics from CMB Polarisation Anisotropies,*
Student: Rajorshi Chandra (IUCAA).

Title: *Study of CMB Spectral Distortions,*
Student: Debajyoti Sarkar (IUCAA).

Title: *Study of Cosmic Microwave Background: Anomalies and Weak Lensing,*
Student: Shabbir Shaikh (IUCAA)

R. Srianand

Title: *Multi-Wavelength Spectroscopic Study of Cold Gas in External Galaxies,*
Student: Rajeshwari Dutta (IUCAA).

(e) SUPERVISION OF PROJECTS

Sheelu Abraham and **Arunima Banerjee**

Prerak Garg (Savitribai Phule Pune University) *Origin of the Low Star Formation Rate in Low Surface Brightness Galaxies: The Disk Instability Approach,* VSP, IUCAA.

Dipankar Bhattacharya

Satyam Agarwal (University of Delhi) *Measuring Earth's Gravity using Satellite Motion,* VSP, IUCAA.

Pravir Kumar (IISER, Bhopal) *The Crab Pulsar at X-ray Bands,* VSP, IUCAA.

Sourav Bhattacharya

Hareram Swain (IISER, Thiruvananthapuram) *Symmetries of Minkowski and de Sitter Sapcetimes,* VSP, IUCAA.

Gulab C. Dewangan

Rohankumar Patel (IIST, Thiruvananthapuram) *Characterising the Point Spread Function of AstroSat/SXT,* VSP, IUCAA.

Kapil Tirpuday (IISER, Pune) *Soft X-ray Study of Active Galactic Nuclei with AstroSat.*

Sanjeev V. Dhurandhar

Divya Singh (IISER, Pune) *Gravitational Waves*.

Girjesh Gupta

Monika Gundecha (Savitribai Phule Pune University) *Properties of Propagating Waves in the Solar Corona.*

Neeraj Gupta

Bhargav Sachin Ghandekar (IITM, Pune) *Introduction to Radio Astronomy.*

Shivan Khullar (BITS - Pilani, Goa) *Observing Nearby Galaxies through HI 21 cm Line.*

Shubhonkar Pramanick (IIST, Thiruvananthapuram) Mass *Modelling of Galaxies through HI 21 cm Line Observations,* VSP, IUCAA.

Co-supervisor
Ayanda Zunga (University of KwaZulu Natal, South Africa) *Evolution of Cold Gas in Galaxies using Absorption Lines.*

Ajit K. Kembhavi

Jay Bhambure (Savitribai Phule Pune University) *Formation of Binaries by Tidal Capture,* VSP, IUCAA.

Nikhil Mukund

Disha P. Kapasi (IISc, Bengaluru) *System Identification using Machine Learning.*

Saurabh Thakur (Vellore Institute of Technology) *Information Retrieval and Recommendation System for Astronomical Observatories.*

Aseem Paranjape

Sioree Ansar (Presidency University, Kolkata) *Redshift Space Distortions: Analytical Models, VSP, IUCAA.*

Swati Gavas (Savitribai Phule Pune Univirsity) *Properties of Dark Matter Haloes in N-body Simulations.*

Shivam Pandey (IIT, Delhi) *Cosmological Void Finder, VSP, IUCAA.*

Sanjana Sekhar (BITS-Pilani, Goa) *Correlation Function of Galaxies, Voids and Void Galaxies, VSP, IUCAA.*

Anupama Sreevalsan (Government College, Madappally, Kerala; and Indian Academy of Sciences, Bengaluru) *Does Cosmological Expansion Affect the Hydrogen Atom?*

Aditya Vidhate (BITS-Pilani, Hyderabad) *Performing Cosmological N-body Simulations.*

Somak Raychaudhury

Gourab Giri (Presidency University, Kolkata)
Evidence of Recent Mergers in Early-type Galaxies.

Chetan Bavdhankar (Savitribai Phule Pune University)
Local Group Motion using Type Ia Supernovae.

Rwitika Chatterjee (IIST, Thiruvananthapuram)

Lekshmi T. (Central University of Tamil Nadu, Thiruvarur)
Probing the Dark Matter Halo of the Milky Way, VSP, IUCAA.

Kanak Saha

Atma Anand (IIST, Thiruvananthapuram) *Long-term Stability of a Star-Planet System in a Near-Keplerian Disk.*

Indrani Das (IIT, Kharagpur) *Orbital Structure in a Lopsided Galaxy,* VSP, IUCAA.

Jayant Jain (BITS, Pilani) *Finding Clumps in Simulated Galaxies.*

R. Srianand

Shubham Agrawal (IIT, Delhi) *Image Stacking of Mg II Absorbers.*

Rachith Aiyappa (BITS - Pilani, Goa) *Physical Conditions in the IGM.*

Anurag Misra (IIST, Thiruvananthapuram) *Probing Cosmology using Primordial Nucleosynthesis*.

Sunil Simha H.S. (IIT - Madras, Chennai) *Modelling Large Scale Outflows from QSOs,* VSP, IUCAA.

Aditya Vijayakumar (Indian Academy of Sciences, Bengaluru) *Extended Emission from the Mg II Absorbers.*

Tarun Souradeep

Debabrata Adak (IUCAA) *Imprints of Anisotropic Reionization on CMB*.

Rajorshi Chandra (IUCAA) *Reconstruction of Lensing Potential from CMB Anisotropies.*

Swanand Khanapurkar (IISER, Pune) *Weak Lensing of the Cosmic Microwave Background.*

Kandaswamy Subramanian

Kishore Gopalakrishnan (BITS, Pilani) *Structure Formation in the Universe.*

Swarnim Shashank (Indian Academy of Sciences, Bengaluru) *Electrodynamics in Curved Spacetime*.

Devika Tharakkal (Central University of Tamil Nadu, Thiruvarur) *Dynamo Generation of Magnetic Fields,* VSP, IUCAA.

Durgesh Tripathi

V.N. Nived (IISER, Pune) *Study of Active Regions with Extreme-Ultraviolet Imaging Spectrometer on-board Hinode*.

(f) SEMINARS, COLLOQUIA, AND LECTURES

Sheelu Abraham

Introduction to Astronomical Data and Virtual Observatory, Sacred Heart College, Chalakudy, July 2016.

Formation Scenario of Bulges of Lenticular Galaxies, University of Calicut, Kozhikode, July 2016.

Machine Learning Applications in Astronomy, BITS - Pilani, Hyderabad, October 2016.

Detection of Barred Galaxies with Convolutional Neural Network, 35th Meeting of the Astronomical Society of India, Jaipur, March 2017.

Arunima Banerjee

Vertical Structure of Disc Galaxies and their Dark Matter Halos, Physics and Applied Mathematics Unit, Indian Statistical Institute, Kolkata, December 2016.

Mass Modelling of Superthin Galaxies, PHISSC Conference, NCRA, Pune, February 2017.

Dipankar Bhattacharya

AstroSat, Department of Physics, Indian Institute of Science, Bengaluru, April 1, 2016.

Lure of Astronomy, Introductory Summer School in Astronomy and Astrophysics, IUCAA, May 16, 2016.

The AstroSat Mission, Indian Academy of Sciences, Bengaluru, July 1, 2016 (invited).

Observing with AstroSat, Department of Physics, University of Southampton, July 26, 2016.

The AstroSat Mission: A Multi-Wavelength Observatory, 11th INTEGRAL Conference, Amsterdam, October 14, 2016 (invited).

Coordinated Timing of the Crab Pulsar with AstroSat CZTI and Radio Observatories, International Conference on Wideband Spectral and Timing Studies of Cosmic X-ray Sources, TIFR, Mumbai, January 13, 2017 (invited).

Multi-wavelength Timing Observations with AstroSat, Team Meeting on Understanding Multi-wavelength Rapid Variability: Accretion and Jet Ejection in Compact Objects, ISSI, Beijing, March 22, 2017 (invited).

Sumanta Chakraborty

Gravity and Thermodynamics: The Importance of being Null, Department of Astroparticle Physics, SISSA, Trieste, June 9, 2016.

Information Retrieval from Black Holes, Department of Physics, INFN and University of Trieste, June 14, 2016.

When Mathematics Meets Physics, National Conference on General Relativity, CCEGR - 2016, Krishnagar Women's College, Krishnanagar, September 6 - 7, 2016.

Sabyasachi Chattopadhyay

DOTIFS: A Multi-deployable Fibre-fed IFU Spectrograph, Leibniz Institute for Astrophysics Potsdam, Berlin, December 13, 2016.

Deployment Scheme and Development of Integral Field Units for Devasthal Optical Telescope Integral Field Spectrograph, 35th Meeting of Astronomical Society of India, Jaipur, March 9, 2017.

Naresh K. Dadhich

Relativity for Everyone, Max Planck Institute for Solar Science, Gottingen, Germany, May 2, 2016; and University of Oldenberg, Germany, June 27, 2016.

Indian Contribution to General Relativity: A Centennial Review, Frankfurt University, Germany, May 17, 2016.

Do we Really Live in Four or in Higher Dimensions, University of Rome, Italy, May 30, 2016; University of Cologne, June 7, 2016; and University of Barcelona, July 14, 2016.

Understanding General Relativity after 100 Years: A Matter of Perspective, Symposium on New Trends in Fundamental and Applied Physics, Tashkent, November 10 -11, 2016; Indian Institute of Science, Bengaluru, December 8, 2016; University of Calcutta, Kolkata, February 14, 2017; Indian Association for Cultivation of Science, *Kolkata, February 16, 2017; University of North Bengal, Siliguri, March 18, 2017; and University of Burdwan, March 30, 2017.*

Gulab C. Dewangan

Using Galaxy Clusters for Response Calibration, AstroSat Calibration Meeting, TIFR, Mumbai, April 12, 2016.

AstroSat - India's First Space Astronomy Mission, European Week of Astronomy and Space Science Meeting, Eugenides Foundation, Athens, Greece, July 4 - 8, 2016 (invited).

AstroSat Proposal Processing System and Preparing AstroSat Proposals, Meeting on AstroSat AO Proposal Submission: Guidelines and Technical Issues, IUCAA, July 13 - 14, 2016.

X-ray Astronomy, Radio Astronomy School, NCRA, Pune, December 21, 2016.

Seyfert Galaxies: AstroSat Results, International Conference on Wide Band Spectral and Timing Studies of Cosmic X-ray Sources, TIFR, Mumbai, January 10 - 13, 2017 (invited).

X-ray/UV Connections in Seyferts, Workshop on Data Analysis and LAXPC Science, TIFR, Mumbai, January 18 - 21, 2017 (invited).

AstroSat Status and Science Support, 35th Meeting of the Astronomical Society of India, Jaipur, March 6 - 10, 2017.

Sanjeev V. Dhurandhar

Detection of Gravitational Waves: Overview, Symposium on Gravitational Waves, Department of Physic, Savitribai Phule Pune University, April 28 - 29, 2016.

Discovery of Gravitational Waves, VSP/Summer School, IUCAA, May - June, 2016.

The Cross-Correlation Search for Stochastic and Continuous Wave Sources of Gravitational Waves, Friedrich-Schiller University, Jena, Germany, June 15, 2016.

Einstein Right Once Again: Gravitational Wave Detection and Astronomy, National Workshop on Gravitational Waves, Dibrugarh University, November 2, 2016 (keynote address); Global Conference on Cosmology and Frontiers of Applied Astro-Science, Ethiraj College, Chennai, February 9, 2017 (invited); and Department of Physics, IIT - Madras, Chennai, February 10, 2017 (invited).

Differential Geometry, National Workshop on Gravitational Waves, Dibrugarh University, November 3, 2016.

Computational Challenges in Gravitational Wave Data Analysis, Workshop on Physics at the Extreme, Penn State, USA, December 1 - 3, 2016 (panel discussion).

Effect of Sine-Gaussian Glitches on Compact Coalescing Binary Searches, Caltech, USA, December 6, 2016.

Data Analysis Techniques for Gravitational Wave Astronomy, Platinum Jubilee International Conference on Applications in Statistics, Department of Statistics, University of Calcutta, Kolkata, December 21, 2016 (invited).

Syzygies in Mathematics and Astronomy, 82th Annual Conference of the Indian Mathematical Society, Kalyani University, December 27, 2016 (invited).

The Cross-Correlation Search for Stochastic Sources of Gravitational Waves, IISER, Thiruvananthapuram, March 9, 2017.

Girjesh Gupta

Role of Waves and Small-Scale Transients in the Heating of Solar Atmosphere, PRL, Ahmedabad, April 7, 2016.

Role of Waves and Small-Scale Transients in the Heating of Solar Corona, IIT, Ropar, August 26, 2016.

Neeraj Gupta

The MeerKAT Absorption Line Survey, Workshop on MeerKAT Science, Cape Town, May 26, 2016.

HI 21 cm Absorption Line Physics and Data Analysis, Workshop on Fourth 3rd Generation Calibration, Cape Town, South Africa, November 2016.

Observing AGNs with Thirty Metre Telescope, Training School in Optical Astronomy with Large Telescopes, IUCAA, January 25, 2017.

Synergies Between TMT and SKA, Training School in Optical Astronomy with Large Telescopes, IUCAA, January 27, 2017.

Ranjan Gupta

Light Scattering Properties of Astrophysical Dust and its Modelling, University of Wuerzberg, Germany, April 4, 2016.

Modelling of Dust using Light Scattering Tools, Short Term Course on Dynamical Systems: Theory and Applications, ISM, Dhanbad, June 26, 2016.

Latest Developments in Light Scattering Tools Applied to Astrophysical Dust, Workshop on Light Scattering, Optics and Fabry-Perot Spectroscopy, Gujarat Science College, Ahmedabad, August 27, 2016.

Basic Astronomy Definitions and Basics of Spectroscopy and Instrumentation, Introductory School on Astronomy, Eliezer Joldan Memorial College, Leh, Ladakh, September 13-14, 2016.

Telescopes and Observations, Workshop on Stellar Astrophysics, Christ University, Bengaluru, February 2, 2017.

Automated Classification of LAMOST DR3 FGK Spectra, International Workshop on Stellar Spectral Libraries, Sao Paulo, Brazil, February 9, 2017.

Ajit K. Kembhavi

Galaxies, VSP/Summer School, IUCAA, May - June 2016.

Ranjeev Misra

AstroSat: A New Era for Rapid X-ray Timing, 35th Meeting of the Astronomical Society of India, Jaipur, March 2016 (invited).

AstroSat: X-ray Binaries, TIFR, Mumbai, August 2016.

Black Holes in the Universe, and *Radiative Processes in Astrophysics,* Workshop on Projects in X-ray Astronomy, Providence College, Kozhikode, November 2016.

AstroSat: Observation of Cygnus X-1 in the Hard State, Conference on Wideband Spectral and Timing Studies of Cosmic X-ray Sources, TIFR, Mumbai, January 2017 (invited).

Sanjit Mitra

Stochastic Gravitational Wave Background, Future of GW Astronomy Conference, ICTS, Bengaluru, April 6, 2016 (invited).

GW @ IUCAA High Performance Computing, National Supercomputing Mission Brainstorming Meeting on Application Development, YASADA, Pune, April 29, 2016.

Stochastic Gravitational Waves: Windows to the Unknowns, IUCAA, December 1, 2016.

Future of Gravitational Wave Astronomy: Indian Potential, 104th Indian Science Congress, Tirupati, January 6, 2017 (invited).

Nikhil Mukund

Gravitational Wave Astronomy, W.M.O. Arts and Science College, Muttil, Wayanad, February 15, 2017 (via Skype).

Machine Learning in LIGO Commissioning and Characterization, LIGO Virgo Collaboration Meeting, Pasadena, California, March 13, 2017.

Newtonian Noise Reduction in Advanced LIGO, LIGO - India: The Road Ahead (LITRA - III) Meeting, IUCAA, March 27, 2017.

Jayant V. Narlikar

The Interaction between Physics, Mathematics and Astronomy, National Chemical Laboratory, Pune, May 6, 2016.

Astronomy Tradition in India, The Finnish Society for Natural Philosophy, Finland, May 17, 2016.

Quasi-steady State Cosmology, The Finnish Society for Natural Philosophy, Finland, May 18, 2016.

What Should One Expect from a Cosmological Model?, International Workshop on Scientific Models and a Comprehensive Picture of Reality, Helsinki, Finland, May 20, 2016.

Physics, Mathematics and Astronomy: A Triangular Interaction, DST INSPIRE Camp, Pt. Ravishankar Shukla University, Raipur, August 11, 2016; and MIT Academy of Engineering, Pune, February 20, 2017.

Gravitational Waves, Institute of Science, Banaras Hindu University, Varanasi, September 2, 2016.

Recent Developments in Astronomy and Astrophysics, Banaras Hindu University, Varanasi, September 3, 2016.

Big Bang Cosmology: Some Reservations, National Institute for Space Research, Brazil, September 27, 2016.

The Physics of Gravitational Waves, National Institute for Space Research, Brazil, September 28, 2016.

The Search for Micro-organisms in the Earth's Atmosphere, National Institute for Space Research, Brazil, September 29, 2016; and Birla Institute of Technology and Science, Pilani, February 10, 2017.

The Amazing World of Astronomy, Pontificia Universidad Católica de Valparaíso, Chile, October 4, 2016.

A Search for Micro-life in the Earth's Atmosphere, XIX Congreso Internacional de Astronomia Amateur - CIAA SAVAL 2016, Chile, October 5, 2016.

Outstanding Problems in Cosmology, Instituto de Astrofisica, Pontificia Universidad Católica, Chile, October 11, 2016.

Search for Micro-life in the Universe, IARC Astrobiology Conference, Nehru Science Centre, Mumbai, October 24, 2016.

Searches for Life outside the Earth, Multi-disciplinary Centre for Advance Research and Studies, Jamia Millia Islamia, New Delhi, February 13, 2017.

Analytical Thinking and Excitement of Doing Science, Birla Institute of Technology, Mesra, Ranchi, March 24, 2017.

T. Padmanabhan

Action Principle in General Relativity, IMSc, Chennai, June 1, 2016.

The Atoms of Spacetime and the Cosmological Constant, Dice 2016 Conference, Castiglioncello, Italy, September 13, 2016.

Cosmic Odyssey: Past, Present and Future, Bologna, Italy, September 20, 2016.

The Atoms of Space and Gravity, Bologna, Italy, September 21, 2016.

Gravity and the Cosmos, ETH Zurich, September 27, 2016; and (P.S. Narayanan Memorial Lecture), IISc, Bengaluru, October 13, 2016.

GR and QG: The Next Hundred Years, Fundamental Problems of Quantum Physics 2016, Discussion Meeting, ICTS, Bengaluru, December 9, 2016.

Mayukh Pahari

Spectro-Temporal Analysis of X-ray Binaries using LAXPC on-board AstroSat, 34th Annual Meeting of the Astronomical Society of India, University of Kashmir, Srinagar, May 9 - 13, 2016.

X-ray Properties of Galactic Micro-quasars using AstroSat/LAXPC, International Conference on Wide Band Spectral and Timing Studies of Cosmic X-ray, Department of Astronomy and Astrophysics, TIFR, Mumbai, January 10 - 12, 2017 (invited).

Aseem Paranjape

Recent Developments in Analytical Modelling of Cosmological Large Scale Structure, Centre for Theoretical Sciences, IIT, Kharagpur, July 20, 2016.

Assembling the Universe, IUCAA, October 6, 2016; and Observatoire de la Cote d'Azur, Nice, France, March 30, 2017.

Niladri Paul

Visualization of N-body Simulations and Constraining Halo Mass Function from it, Workshop on Statistical Analysis in Cosmology, CUSAT, Kochi, January 12, 2017.

Calculation of Correlation Function of Halos, Workshop on Statistical Analysis in Cosmology, CUSAT, Kochi, January 13, 2017.

Somak Raychaudhury

Gravitational waves: ripples in the fabric of spacetime. Professor Tapas Majumdar Memorial Lecture, Presidency University Alumni Association (Delhi Chapter), Habitat Centre, New Delhi, April 16, 2016.

Big Data Astronomy in India, **Pre-ASI Workshop** on *Big Data in Astronomy, University of Kashmir, Srinagar, May 9, 2016.*

SALT Science at IUCAA (2015-16), SALT Science Symposium, American Museum of Natural History, New York, June 1, 2016.

Gravitational waves: ripples in the fabric of spacetime. Pune International Centre PIC-ADDA, Pune, July 16, 2016.

How to find black holes. DST-INSPIRE camp at IISER Pune, July 21, 2016.

New Algorithms for Astronomical Discovery, Keynote address atUGC-sponsored National Level conference on *Innovative trends in mathematics and its applications*at Sri Sikshayatan College, Kolkat,. August 3, 2016.

Our Place in Space, Second Saturday talk for school students, IUCAA, Pune, August 13, 2016.

Observing stellar mass and Supermassive black holes, two talks at the *Introductory Workshop on Astrophysics and Cosmology*, Aliah University, Kolkata, September 27-28, 2016

A black hole hunter's essential toolkitWeekly Physics Colloquium (celebrating 100th of the series) at Presidency University, Kolkata, September 28, 2016

Gravitational Waves: Ripples in the fabric of Spacetime Evening talk at Persistent Systems Limited, Pune, December 11, 2016.

Gravitational Waves: LIGO-India Invited talk, Advanced school on gravitational waves, Presidency University, Kolkata, December 12-15, 2016.

Radio galaxies in groups and clusters: effect of local environment, invited talk in Wide Band Spectral and Timing Studies of Cosmic X-ray Sources, Tata Institute for Fundamental Research, Mumbai, January 10-13, 2017.

Innovations in Science and Technology in India, Global Educational Summit, Chairman's introduction at Presidency University Kolkata Bicentenary Event, January 17, 2017.

Science and Enterprise, invited talk and discussion at the Kolkata Literary Meet, Victoria Memorial grounds, Kolkata, January 27, 2017.

Going to Space to see the Sky, TEDX talk, Jadavpur University, Kolkata, 27 January 27, 2017, https://youtu.be/j2-g82O9tfE.

How to find black holes invited talk at the Frontiers in Physics workshop, Fergusson College, Pune, 3 February 2017.

Gravitational Waves: Future Mega-Science Mission for India, Lunar and Planetary Exploration Group Endowment Lecture, XXXI Gujarat Science Congress, GERMI, Gandhinagar, February 5, 2017.

Kanak Saha

AstroSat/UVIT Deep Observation of HST/Chandra Deep Field South, 35th Annual Meeting of the Astronomical Society of India, Jaipur, March 8, 2017.

Long-Lived Spiral Structure in Disk Galaxies, Department of Physics, Indian Institute of Science, Bengaluru, March 28, 2017 (invited).

Varun Sahni

Reconstructing Dark Energy, International Conference on New Tendencies of Developing Fundamental and Applied Physics: Problems, Achievements and Perspectives, Tashkent, Uzbekistan, November 10, 2016.

Tarun Souradeep

Beyond the First Discoveries with LIGO - India, Symposium on Gravitational Waves, 27th Meeting of IASc, Bengaluru, July 2, 2016.

LIGO - India: Beyond the Discovery of Gravitational Waves, NWGWA 2016, Dibrugarh University, November 2, 2016; and IUCAA - South Africa Meeting on Cosmology, IUCAA, November 24 - 25, 2016.

Enigmatic Cosmic Hemispherical Asymmetry, 3rd Saha Theory Workshop, SINP, Kolkata, January 16 - 17, 2017.

LIGO-India, LIGO-Virgo Collaboration Meeting, Pasadena, USA, March 15, 2017.

R. Srianand

Probing the Universe and Fundamental Physics with QSOs Absorption Lines, ARIES, May 2016 (invited).

uGMRT and TMT, Workshop on Science with uGMRT, NCRA, Pune, June 2016 (invited).

Probing the Universe with QSO Absorption Line, NISER, Bhubaneswar, November 2016 (invited).

UV Ionizing Background at z < 0.5, Workshop on Probing the Baryons in the Universe, Paris, November 2016 (invited).

Kandaswamy Subramanian

Origin of Cosmological Magnetic Fields: Primordial and Dynamos, 34th Annual Meeting of the Astronomical Society of India, Srinagar, May 2016 (invited).

The First Magnetic Fields, Indian Institute of Science, Bengaluru, June 2016 (invited).

Challenges in Understanding Cosmic Magnetism, Raman Research Institute, Bengaluru, June 2016 (invited).

Durgesh Tripathi

Updates on the Solar Ultraviolet Imaging Telescope, VELC Meeting, Bengaluru, September 8 - 19, 2016.

The Solar Ultraviolet Imaging Telescope on Board Aditya-L1, IIT, Kanpur, October 17, 2016; and 35th Annual Meeting of the Astronomical Society of India, Jaipur, March 6 -10, 2017.

Coupling and Dynamics of the Solar Atmosphere, IISER, Mohali, Meeting of the Max-Planck Partner Groups in India, IISER, Mohali, March 3 - 5, 2017.

(g) LECTURE COURSES

Varun Bhalerao

X-ray Astronomy/Transients (4 lectures), VSP/Summer School, IUCAA, May - June 2016.

Dipankar Bhattacharya

Stellar Structure (4 lectures), VSP/Summer School, IUCAA, May - June 2016.

Sukanta Bose and **Sanjit Mitra**

General Relativity/Gravitational Waves (6 lectures), VSP/Summer School, IUCAA, May - June 2016.

Gulab C. Dewangan

X-ray Astronomy and Active Galactic Nuclei (2 lectures), VSP/Summer School, IUCAA, May - June 2016.

Neeraj Gupta

ISM and Radio Astronomy (4 lectures), VSP/Summer School, IUCAA, May - June 2016.

Ranjan Gupta

Spectroscopy and Instrumentation (2 lectures), VSP/Summer School, IUCAA, May - June 2016.

Basics of Astronomy (4 lectures), IMD-CTI, Pune as a part of Advance Meteorological Training Course (AMTC – Batch 177) for Naval officers and IMD recruits, December 27 - 28, 2016.

Ranjeev Misra

Radiative Processes (2 lectures), VSP/Summer School, IUCAA, May - June 2016.

T. Padamanabhan

Geometry of Space and Spacetime (4 lectures), VSP/Summer School, IUCAA, May - June 2016; and (5 lectures), IISER, Thiruvananthapuram, June 6 - 9, 2016.

Geometry of Spacetime (4 lectures), IISER, Mohali, October 31 - November 3, 2016.

Aseem Paranjape

Cosmology with Large Scale Structure (3 lectures), VSP/Summer School, IUCAA, May - June 2016.

Analytical Techniques for Large Scale Structure (4 lectures), Workshop on *Structure Formation in Standard Cosmology*, BITS - Pilani, Hyderabad, December 19 -23, 2016.

Peak Statistics and Baryon Acoustic Oscillations (2 lectures), Workshop on *Statistical Analysis in Cosmology,* CUSAT, Kochi, January 12 -14, 2017.

A.N. Ramaprakash

Optical Astronomy (2 lectures), VSP/Summer School, IUCAA, May - June 2016.

Somak Raychaudhury

Introduction to Astronomy (4 lectures), VSP/Summer School, IUCAA, May - June 2016.

Kanak Saha

Galaxy Dynamics (4 lectures), VSP/Summer School, IUCAA, May - June, 2016.

Periodic Orbits and Poincare Section for Dynamical System (2 lectures), Short Term Course on Dynamical Systems: Theory and Applications, ISM, Dhanbad, June 26 - 30, 2016.

Galaxy Simulations (2 lectures), Galaxy Formation and Evolution: Models to Interpret Observations, 2nd Info-French School, Lyon, France, July 10 - 16, 2016.

Varun Sahni

Dark Matter/Dark Energy (2 lectures), VSP/Summer School, IUCAA, May - June 2016.

Shabbir Shaikh

Introduction to Markov Chain Monte Carlo (2 lectures), Workshop on Statistical Analysis in Cosmology, CUSAT, Kochi, January 12 - 14, 2017.

Tarun Souradeep

Cosmology (4 lectures), VSP/Summer School, IUCAA, May - June 2016.

Measuring the Perturbed Universe (2 lectures), Workshop on Statistical Analysis in Cosmology, CUSAT, Kochi, January, 12 -14, 2017.

R. Srianand

Inter-Galactic Medium (3 lectures), VSP/Summer School, IUCAA, May - June 2016.

Observational Probes of Structures (4 lectures), Workshop on Structure Formation and Standard Cosmology, BITS - Pilani, Hyderabad, December 19 - 23, 2016.

Introduction to Astronomical Spectroscopy (4 lectures), Training School in Optical Astronomy with Large Telescopes, IUCAA, January 16 - 27, 2017.

Kandaswamy Subramanian

Fluids and Plasmas (4 lectures), VSP/Summer School, IUCAA, May - June 2016.

Shyam N. Tandon

Detectors and Instrumentation (3 lectures), VSP/Summer School, IUCAA, May - June 2016.

Durgesh Tripathi

Solar Physics/The Sun (3 lectures), VSP/Summer School, IUCAA, May - June 2016.

Solar Physics (3 lectures), D.D.U. University of Gorakhpur, August 2016.

Introduction to Solar Physics (4 lectures), Workshop on Introduction to Solar Astrophysics, M.A. College, Kothamangalam, November 30 - December 2, 2016.

(h) POPULAR/PUBLIC LECTURES

Gulab C. Dewangan

Exploring the Universe at X-rays, Jaipur Engineering College and Research Centre, March 6, 2017.

Sanjeev V. Dhurandhar

Einstein's Centennial Gift: Gravitational Waves Discovered, Marathi Vidnyan Parishad, Bal Gandharva Rangamandir, Pune, May 29, 2016; and CHARUSAT University, Anand, Gujarat, July 23, 2016.

Einstein Right Once Again: Gravitational Wave Detection and Astronomy, Nehru Planetarium, Mumbai, October 15, 2016; Institute for Science and Religion, Pune, January 20, 2017; Fergusson College, Pune, February 3, 2017; and Department of Physics, Savitribai Phule Pune University, March 3, 2017.

Gravitational Wave Detection and Astronomy, XVII Meeting of the Indian Association of Physics Teachers, Goa Regional Council, January 28, 2017.

Gravitational Waves and LIGO - India, National Science Day, IUCAA, February 28, 2017.

Sanjeet Mitra

What Gravitational Waves Haven't Told Us Yet? , TEDx Event, VIT, Pune, April 9, 2016.

Gravitational Waves: The Dawn of a New Era in Astronomy, NIT, Warangal, October 21, 2016.

LIGO - India: Prospects and Challenges, Government College of Engineering, Pune, March 1, 2017.

Jayant V. Narlikar

Search for Life in the Universe, Defence Research and Development Organization, Dr. A.P.J. Abdul Kalam Auditorium, Pune, April 12, 2016.

Cosmic Illusions, 2nd Saturday Lecture Demonstration Programme, IUCAA, July 9, 2016.

Disate tase nasate ... kadhi kadhi (Cosmic Illusions) (in Marathi), 2nd Saturday Lecture Demonstration Programme, IUCAA, July 9, 2016.

Convocation Address, Pt. Ravishankar Shukla University, Raipur, August 10, 2016.

Sarjanshilta ani vidnyankathancha pravas (Creativity and Growth of Science Fiction) (in Marathi), R.J. College of Arts, Science and Commerce, Mumbai, August 13, 2016.

Homi Sethna : A Personal Tribute, Nehru Centre, Mumbai, August 24, 2016.

Mahamana ke sapanonka ek adarsha vishwavidyalaya (An Ideal University Dreamt by the Mahamana) (in Hindi), Banaras Hindu University, Varanasi, September 5, 2016.

How Well Do we Know our Universe?, Veermata Jijabai Technological Institute, Mumbai, December 24, 2016.

Antaralatun yenare vichitra varshav (Strange Showers from Space) (in Marathi), Netaji Subhas Chandra Bose Bachat Gat, Parbhani, January 14, 2017.

Khagolshastratil antare (Distances in Astronomy) (in Marathi), AASTRONOMICA Club, N.M.V. Girls' High School, Pune, February 18, 2017.

Pruthvipalikade jeevshrusticha shodh (Searches for Life outside the Earth) (in Marathi), Janseva Kendra, Borivali, March 11, 2017.

The Lighter Side of Gravity, Marathi Vidnyan Parishad and Yashantrao Chavan Pratisthan, Mumbai, March 14, 2017.

Convocation Address, Birla Institute of Technology, Mesra, Ranchi, March 24, 2017.

Institution Building, Birla Institute of Technology, Mesra, Ranchi, March 24, 2017.

Astronomy and Computing: A Personal Experience of Early Days, C-DAC Foundation Day Lecture, IUCAA, March 28, 2017.

T. Padmanabhan

Einstein's Gravity: The First and the Next 100 years, BARC, Trombay, January 12, 2017.

The Frontier of Theoretical Physics, University College, Thiruvananthapuram, February 8, 2017.

Gravity: The Enigma, M.G. College, Thiruvananthapuram, February 9, 2017.

Understanding our Universe: Status and Prospects, Chavan Centre and Marathi Vidnyan Parishad, Mumbai, February 10, 2017.

Aseem Paranjape

The Story of the Accelerating Universe, Fergusson College, Pune, as part of the Frontiers in Physics Programme, February 4, 2017.

Somak Raychaudhury

IUCAA's role in Astronomy Education and Outreach
Astronomical Society of India meeting at BISR, Jaipur, March 6, 2017.

Radio/TV Interviews
(Include on page 91 after Jayant Narlikar)

Eureka with Prof Somak Raychaudhury, interview on Rajya Sabha TV, recorded at ASI meeting at Jaipur, first telecast 10 April 2017,
https://youtu.be/If701Yp_I0Q

Kanak Saha

Galaxies in our Universe, Jaipur Engineering College and Research Centre, March 7, 2017.

Tarun Souradeep

Beyond Gravitational Waves Discovery with LIGO - India, KSCSTE, Thiruvananthapuram, June 2, 2016.

LIGO - India: Beyond the Discovery of Gravitational Waves, Olympiad National Camp, HBCSE, Mumbai, June 6, 2016; and IAPT Seminar, St. Xavier's College, Mumbai, February 27, 2017.

(i) RADIO/TV PROGRAMMES

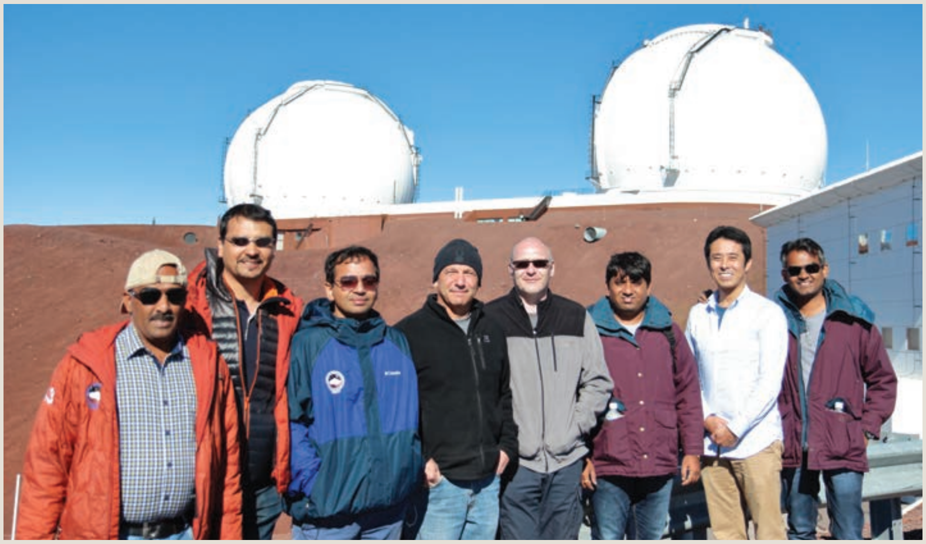
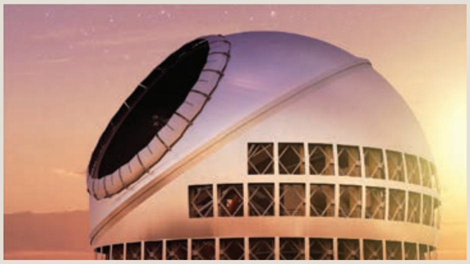
Sanjeev V. Dhurandhar

Gravitational Waves Discovered (interview), All India Radio, Dibrugarh, November 5, 2016.

Jayant V. Narlikar

Vidnyanjanahitay (in Marathi), All India Radio, Mumbai, October 24, 2016

THIRTY METRE TELESCOPE


IUCAA, on behalf of India-TMT, is responsible for delivering the TCS to the TMT International Observatory (TIO). The first phase of the project started on April 5, 2016 with a kick-off meeting at IUCAA. The IUCAA members involved in the TMT- TCS project are Neeraj Gupta, Sujit Punnadi and A. N. Ramaprakash.
(For details see Khagol, No. 107, July 2016)

INTRODUCTORY SUMMER SCHOOL IN ASTRONOMY AND ASTROPHYSICS



The biennial Introductory Summer School in Astronomy and Astrophysics for college and university students was held during May 16 to June 17, 2016 at IUCAA. The faculty coordinator for the school was Aseem Paranjape.
(For details see Khagol, No. 107, July 2016)

VACATION STUDENTS' PROGRAMME

The Vacation Students' Programme (VSP), for students in their penultimate year of M.Sc. (Physics) or engineering degree course was held during May 16 to July 1, 2016. R. Srianand was the faculty coordinator of this programme. (For details see Khagol, No. 107, July 2016)

VISIT OF MAHARASHTRA CHIEF MINISTER SHRI DEVENDRA PHADNAVIS

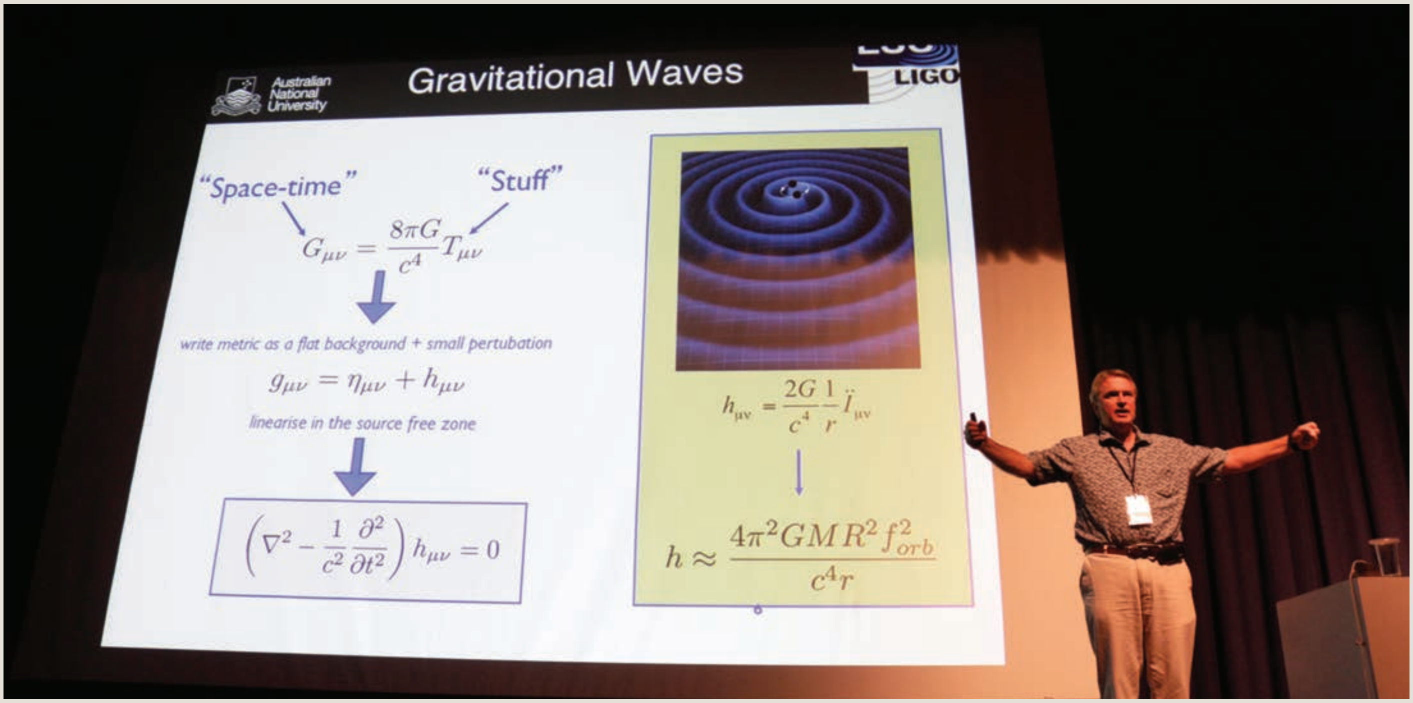
The Chief Minister of Maharashtra, Shri Devendra Fadnavis, visited IUCAA campus on September 23, 2016. During his short stay, the Director, along with Tarun Souradeep and Ajit Kembhavi briefed him about IUCAA's involvement in LIGO-India, and the work being done in the selection of its site.

(For details see Khagol, No. 108, October 2016)

ONE YEAR OF Astrosat

On September 28, 2016, India's first dedicated astronomical satellite, AstroSat, completed its first year of successful operation. To celebrate the occasion, a one day science meeting was organised at IUCAA on Thursday, September 29, 2016. Ranjeev Misra was the coordinator of this meeting.
(For details see Khagol, No. 108, October 2016)

LIGO - INDIA: THE ROAD AHEAD



The first LIGO-India specific meeting, since it received in-principle approval from the Government of India earlier this year, was held at IUCAA during August 16 - 18, 2016.
(For details see Khagol, No. 108, October 2016)

SUIT PAYLOAD ON ADITYA-L1: MOU WITH ISRO

The Director, Somak Raychaudhury, has signed a Memorandum of Understanding (MoU) with M. Annadurai, the Director of the ISRO Satellite Centre (ISAC) in Bengaluru, on September 15, 2016.
(For details see Khagol, No. 108, October 2016)

VISIT OF UK SECRETARY OF STATE FOR INTERNATIONAL TRADE

Rt. Hon. Dr. Liam Fox, the UK Secretary of State for International Trade, visited IUCAA on November 9, 2016. (For details see Khagol, No. 109, January 2016)

THE 28TH FOUNDATION DAY LECTURE

IUCAA Foundation Day Lecture was delivered on December 29, 2016 by Ramakrishna Ramaswamy, currently at the School of Physical Sciences and the Centre for Computational Biology and Bioinformatics, Jawaharlal Nehru University, New Delhi.
(For details see Khagol, No. 109, January 2017)

INTERNATIONAL CONFERENCE ON ORIENTAL ASTRONOMY

The International Conference on Oriental Astronomy (ICOA) was organized during November 15 - 18, 2016, at the Indian Institute of Science Education and Research (IISER), Pune (Partly funded by IUCAA).

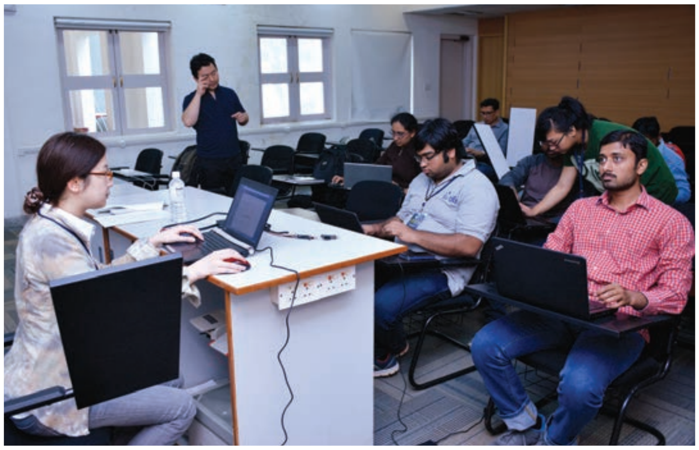
(For details see Khagol, No. 109, January 2017)

WORKSHOP ON ASPECTS OF GRAVITY AND COSMOLOGY

A workshop on Aspects of Gravity and Cosmology was organised at IUCAA, during March 7 - 9, 2017, covering a broad range of topics in classical and quantum aspects of gravitation and cosmology. The coordinators of this workshop were Aseem Paranjape (IUCAA) and Tirthankar Roy Choudhury (NCRA, Pune).

(For details see Khagol, No. 110, April 2017)

TRAINING SCHOOL ON OPTICAL ASTRONOMY WITH LARGE TELESCOPES



As a part of the Thirty Metre Telescope - India (TMT - India) project, a Training School on Optical Astronomy with Large Telescopes was organised at IUCAA, during January 16 - 27, 2017. The workshop was funded by India TMT Coordination Centre (ITCC), and coordinated by R. Srianand, Neeraj Gupta and A. N. Ramaprakash.
(For details see Khagol, No. 110, April 2017)

TOPICAL COURSE ON COMPUTATIONAL STATISTICS AND ASTRO-STATISTICS

A Topical Course on Computational Statistics and Astro-Statistics was held at IUCAA, during January 2 - 10, 2017. Ranjan Gupta (IUCAA) was the coordinator of the course.
(For details see Khagol, No. 110, April 2017)

Ph.D. Programme

During the year of this report, four IUCAA Research Scholars have defended their Ph.D. theses, namely: **Sumanta Chakraborty** (Guide: T. Padmanabhan), **Vikram Khaire** (Guide: R. Srianand), **Nagendra Kumar** (Guide: Ranjeev Misra) and **Suvodip Mukherjee** (Guide: Tarun Souradeep). Their Ph.D. degrees have been awarded by the Jawaharlal Nehru University, New Delhi. The synopses of their theses are given below:

Sumanta Chakraborty

CLASSICAL AND QUANTUM ASPECTS OF GRAVITY IN RELATION TO THE EMERGENT PARADIGM

General Relativity is a very successful theory and is the best formalism we have to describe the geometrical properties of the spacetime. It has passed all the experimental and observational tests so far, ranging from local tests like perihelion precession and bending of light to precision tests using pulsars.

In spite of these outstanding successes, there still remains some unresolved issues, suggesting that general relativity is not complete. The most important reason is the presence of singularities in many physical situations leading to a loss of predictability. Another reason is that the horizons in general relativity possess thermodynamic properties like temperature and entropy. Within the framework of general relativity, there is no natural explanation for this "thermodynamic" interpretation and it provides motivation to take a fresh look at the theory. A third reason arises from the fact that all the other known interactions (electromagnetic, weak and strong) are described by quantum theories, while gravity alone is still described by a classical theory. This laid the foundation to believe that "quantum theory of gravity" awaits discovery. The attempts to obtain a perturbative quantum general relativity, taking a cue from the quantization of the other forces, have not succeeded. This has the unavoidable conclusion: we need to modify our understanding of quantum field theory or the understanding of general relativity or both.

In this thesis, we try to understand the thermodynamic nature of general relativity better by taking a closer look at the structure of general relativity and its higher curvature cousins, collectively called Lanczos-Lovelock gravity. If one can derive a result in the context of Lanczos-Lovelock gravity, the result for general relativity is encompassed by it as well. We shall analyze the geometrical structure of Lanczos-Lovelock gravity (which has general relativity as a special case) leading to the inescapable connection between gravity and thermodynamics. We also have discussed about Virasoro algebra associated with an arbitrary null surface and associated entropy in this context.

As a complementary approach towards a quantum theory of gravity, we study some aspects of quantum field theory in curved spacetime. The specific issues addressed in this context, include: (a) What can we say about classical singularities from the viewpoint of quantum theory? This specifically requires one to probe quantum fields inside the black hole horizon. (b) Is the retrieval of information from an evaporating black hole possible? (We will show that distortions to the thermal spectra of a particular kind, referred to as non-vacuum distortions can be used to fully reconstruct a subspace of initial data.) (c) Can Rindler effect be present for geodesic observers? We illustrate for a specific (1+1) black hole spacetime, there are geodesic observers who are confined to a flat region of the spacetime and hence will experience Rindler effect.

Finally, in order to capture some quantum gravity effects, we have introduced a zero point length to the spacetime and have discussed its geometrical consequences. In particular, we have shown that at the Planck scale the spacetime becomes essentially two-dimensional.

Apart from the introduction and the conclusion, the thesis is divided into four parts discussing each of these ideas separately.

In the first part of the thesis, We start by reviewing the structure of Einstein-Hilbert Lagrangian density $\sqrt{-g}L_{\rm EH}$ in terms of a particular dynamical variable $f^{ab}=\sqrt{-g}g^{ab}$ and its corresponding canonical momenta $N^a_{bc}=-\Gamma^a_{bc}+\frac{1}{2}\left(\Gamma^d_{bd}\delta^a_c+\Gamma^d_{cd}\delta^a_b\right)$. After providing the introduction to general relativity using these variables, we generalize the action principle from general relativity to Lanczos-Lovelock models of gravity. In both these cases, i.e., general relativity and Lanczos-Lovelock gravity, we discuss the structure of Noether current and its thermodynamic interpretation. Then we go on to show that the conjugate variables f^{ab} and N^a_{bc} are not suitable for Lanczos-Lovelock gravity, even though they were very suitable for describing general relativity. We identify another new set of variables, using which both general relativity and Lanczos-Lovelock gravity can be described, and they are also conjugate to one another.

The second part is devoted in exploring the connection between gravity and thermodynamics. The geometrical variables f^{ab} and N^c_{ab} can also have thermodynamic interpretation. In case of Lanczos-Lovelock gravity as well, we could introduce two suitable variables with the following properties: (a) These variables reduce to the ones used in general relativity in $D=4$ when the Lanczos-Lovelock model reduces to general relativity. (b) The variation of these quantities correspond to $s\delta T$ and $T\delta s$, where s is now the correct Wald entropy density of the Lanczos-Lovelock model. This result holds rather trivially on any static (but not necessarily spherically symmetric or matter-free) horizon and — more importantly — on any arbitrary null surface acting as local Rindler horizon. The analysis once again confirms that the thermodynamic interpretation goes far deeper than general relativity and is definitely telling us something non-trivial about the structure of the spacetime.

In the case of general relativity, one can interpret the Noether charge in any bulk region as the heat content TS of its boundary surface. Further, the time evolution of spacetime metric in Einstein's theory arises due to the difference $(N_{\rm sur}-N_{\rm bulk})$ of suitably defined surface and bulk degrees of freedom. We show that this thermodynamic interpretation generalizes in a natural fashion to all Lanczos-Lovelock models of gravity. Padmanabhan has previously obtained several additional results strengthening the above connection within the framework of general relativity. Here we provide a generalization of the above setup to Lanczos-Lovelock gravity as well. As expected, most of the results obtained in the context of general relativity generalize to Lanczos-Lovelock gravity in a straightforward *but* non-trivial manner. Another interesting feature of gravity is that gravitational field equations for arbitrary static and spherically symmetric spacetimes with horizon can be written as a thermodynamic identity in the near horizon limit. This result holds in both general relativity and in Lanczos-Lovelock gravity as well. Previously it was known that, for an arbitrary spacetime, the Einstein's equations near any null surface generically leads to a thermodynamic identity. Here we generalize this result to Lanczos-Lovelock gravity by showing that gravitational field equations for

Lanczos-Lovelock gravity near an arbitrary null surface can be written as a thermodynamic identity. Our general expressions under appropriate limits reproduce previously derived results for both the static and spherically symmetric spacetimes in Lanczos-Lovelock gravity. Also by taking appropriate limit to general relativity, we can reproduce the results derived earlier.

We have also emphasized how the emergent gravity paradigm interprets gravitational field equations as describing the thermodynamic limit of the underlying statistical mechanics of microscopic degrees of freedom of the spacetime. We explore the consequences of this paradigm for an arbitrary null surface and highlight the *thermodynamic* significance of various *geometrical* quantities. In particular, we show that: (a) A conserved current, associated with the time development vector in a natural fashion, has direct thermodynamic interpretation in all Lanczos-Lovelock models of gravity. (b) One can generalize the notion of gravitational momentum, introduced by Padmanabhan to all Lanczos-Lovelock models of gravity such that the conservation of the total momentum leads to the relevant field equations. (c) The thermodynamic variational principle which leads to the field equations of gravity can also be expressed in terms of the gravitational momentum in all Lanczos-Lovelock models. (d) Three different projections of gravitational momentum related to an arbitrary null surface in the spacetime lead to three different equations, all of which have thermodynamic interpretation. The first one reduces to a Navier-Stokes equation for the transverse drift velocity. The second can be written as a thermodynamic identity $TdS = dE + PdV$. The third describes the time evolution of the null surface in terms of suitably defined surface and bulk degrees of freedom.

When a null surface is perceived to be a one-way membrane by a particular congruence of observers, they will associate an entropy with it. We derive the form of this entropy, associated with a null surface in a remarkably local manner. It seem reasonable that all physics, including thermodynamics of horizons, must have a proper local description, since operationally, all the relevant measurements will be local. The locality in our derivation is based on three important facts: (i) We have considered diffeomorphisms near the null surface and have used only the structural features of the metric near and on the surface. (ii) We have invoked the behaviour of the boundary term in the action under diffeomorphism in the limit of null surface without any bulk construction, and (iii) We show that a local version of the Cardy formula does give the correct answer. This directly links inaccessibility of information with entropy, which is gratifying. Further, the result is valid for a very wide class of null surfaces and also for arbitrary spacetime dimensions. All the previous results known in the literature (in the context of black holes, cosmology, non-inertial frames and so on) became just special cases of this very general result, which will be useful in further investigations.

In the third part of the thesis, we consider quantum field theory in curved spacetimes. We start with quantum field theory in the background geometry of a collapsing spherical dust ball, to determine whether energy density in the quantum field could be large enough to avoid the singularity. Following this line of thought, we solve the Klein-Gordon equation for a scalar field, in the background geometry of a dust cloud collapsing to form a black hole, everywhere in the (1+1) spacetime: that is, both inside and outside the event horizon and arbitrarily close to the curvature singularity. This allows us to determine the regularized stress tensor expectation value, everywhere in the appropriate quantum state (viz., the Unruh vacuum) of the field. We use this to study the behaviour of energy density and the flux measured in local inertial frames for the radially freely falling observer at any given event. Outside the black hole, energy density and flux lead to the standard results expected from the Hawking radiation emanating from the black hole, as the collapse proceeds. Inside the collapsing dust ball, the energy densities of both matter and scalar field diverge near the singularity in both (1+1) and (1+3) spacetime dimensions; but the energy density of the field dominates over that of classical matter. In the (1+3) dimensions, the total energy (of both scalar field and classical matter) inside a small spatial volume around the singularity is finite (and goes to zero as the size of the region goes to zero) but the total energy of the quantum field still dominates over that of the classical matter. Inside the event horizon, but *outside* the collapsing matter, freely falling observers find that the energy density and the flux diverge close to the singularity. In this region, even the integrated energy inside a small spatial volume enclosing the singularity diverges. This result holds in both (1+1) and (1+3) spacetime dimensions with a *milder* divergence for the total energy inside a small region in (1+3) dimensions. These results suggest that the back-reaction effects are significant even in the region *outside the matter but inside the event horizon*, close to the singularity.

Another key issue is the black hole information loss paradox, which is a long-standing tussle between laws of black hole thermodynamics and unitary quantum evolution. The crux of the paradox lies in the fact that the complete information about the initial state which collapses to form a black hole becomes unavailable to future asymptotic observers, contrary to the expectation from a unitary quantum theory of evolution. Classically nothing else, apart from mass, charge and angular momentum is expected to be revealed to such asymptotic observers after the formation of a black hole. However, semi-classically, black holes evaporate after their formation through the Hawking radiation. The dominant part of the radiation is expected to be thermal, therefore, even when the black hole evaporates completely, one is not supposed to know much about the initial data from the resultant radiation. However, there can be sources of distortions which make the radiation non-thermal. Although the distortions are not strong enough to make the evolution unitary, these distortions are expected to carry some part of information regarding the in-state. Here, we do an analysis regarding the characterization of the state of the field, which undergoes a collapse from the point of view of information they encode in the resultant evaporation spectrum. We show that distortions of a particular kind (which we call *non-vacuum distortions*) can be used to *fully* reconstruct a subspace of initial data. Although, the complete information about the in-state is not encoded and hence is generally non-retrievable completely from the distorted spectra, we identify a class of in-states capable of doing so for spherically symmetric collapse model. We also show that amount of information that is encoded is related to the symmetries of the initial data. Using a (1+1) Callan-Giddings-Harvey-Strominger (in short, CGHS) model to accommodate back-reaction self consistently, we show, using different sets of observers, that one can infer more information about the initial data. Implications of such information extraction are also discussed in this thesis.

We also present a dynamic version of the Unruh effect in a two dimensional collapse model forming a black hole. In this two-dimensional collapse model, a scalar field coupled to the dilaton gravity (i.e., the CGHS model), moving leftwards, collapses to form a black hole. There are two sets of asymptotic ($t \to \infty$) observers, around $x \to \infty$ and $x \to -\infty$. The observers at the right null infinity witness a thermal flux of radiation associated with time dependent geometry leading to a black hole formation and its subsequent Hawking evaporation, as expected. We show that even the observers at left null infinity witness a thermal radiation, without experiencing any change of spacetime geometry all along their trajectories. They remain geodesic observers in a flat region of spacetime. Thus,these observers measure a late time thermal radiation, with *exactly the same* temperature as measured by the observers at right null infinity, *despite moving geodesically in flat spacetime throughout their trajectories*. However, such radiation, as usual in the case of Unruh effect, has zero flux, unlike the Hawking radiation seen by the observers at right null infinity. We highlight the conceptual similarity of this phenomenon with the standard Unruh effect in flat spacetime.

In the last part of the thesis, we discuss the consequences of introducing a zero-point length and its possible implications for quantum gravity. We start by motivating the general belief, that any quantum theory of gravity should have a generic feature — a quantum of length. Following earlier works of Padmanabhan, we provide a physical ansatz to obtain an effective *non-local* metric tensor starting from the standard metric tensor, such that the spacetime acquires a zero-point-length ℓ_0 of the order of the Planck length L_P. This prescription leads to several remarkable consequences. In particular, the Euclidean volume $V_D(\ell, \ell_0)$ in a D-dimensional spacetime of a region of size ℓ scales as $V_D(\ell, \ell_0) \propto \ell_0^{D-2}\ell^2$ when $\ell \sim \ell_0$, while it reduces to the standard result $V_D(\ell, \ell_0) \propto \ell^D$ at large scales ($\ell \gg \ell_0$). The appropriately defined effective dimension, $D_{\rm eff}$, decreases continuously from $D_{\rm eff} = D$ (at $\ell \gg \ell_0$) to $D_{\rm eff} = 2$ (at $\ell \sim \ell_0$). This suggests that the physical spacetime becomes essentially 2-dimensional near Planck scale.

Vikram Khaire

INTERGALACTIC MEDIUM AND COSMIC BACKGROUND RADIATION

Cosmic background radiation from extreme ultraviolet (UV) to far-infrared (FIR) wavelengths and its redshift evolution are the essential pieces of information required to study variety of astrophysical systems and phenomena. These include the reionization of hydrogen and helium, the physical and chemical properties of the intergalactic medium (IGM), the propagation of high energy γ-ray through IGM, etc. The spectrum of cosmic background radiation at different epochs can not be directly observed. There are a few interactions that can be used to infer its integrated intensity at some range of wavelengths and cosmic epochs. However, the spectrum of cosmic background radiation can be modeled theoretically by calculating precisely the radiation emitted by the existing sources and the attenuation suffered by this radiation while traveling through the IGM.

The cosmic background radiation can be categorized into two ranges of wavelengths, one at $\lambda < 0.1\,\mu$m (extreme UV regime) known as the UV background (UVB) and other at $0.1 < \lambda < 1000\,\mu$m (from UV to FIR regime) known as the extragalactic background light (EBL). The UVB is responsible for ionizing hydrogen and helium in the IGM. Therefore, it gets severely affected by the IGM. Whereas the EBL photons pass through IGM nearly unattenuated.

In this thesis, we address the issues related to the theoretical modeling of the spectrum of cosmic background radiation. We developed a cosmological radiative transfer code to estimate it. We use this code to study the implications of different observational inputs for the resultant spectrum of the cosmic background radiation. Main uncertainties in the theoretical modeling arise from uncertainties in the emissivity of the sources. The standard sources of cosmic background radiation are galaxies and QSOs. Contribution of QSOs to the cosmic background radiation is straight-forward to estimate from the luminosity functions of QSOs at different epochs and their average spectral energy distribution (SED).

Whereas to estimate the precise contribution of galaxies, one needs to derive the global average star formation and dust attenuation history and an estimate of an observationally ill-constrained parameter known as escape fraction ($f_{\rm esc}$). The $f_{\rm esc}$ is an average fraction of H I ionizing photons ($\lambda \leq 912$ Å) that escapes through the interstellar medium of the galaxies in to the IGM. $f_{\rm esc}$ decides the galaxy contribution to the UVB. Using our code, we systematically address the issues related to the relative contribution of galaxies and QSOs to the cosmic background radiation. These are briefly described below:

- **Effect of $f_{\rm esc}$ on the UVB**
  QSOs can ionize H I, He I and He II due to their hard SED, whereas galaxies can only ionize H I and He I. Using our code developed to calculate the spectrum of cosmic background radiation, we show that the $f_{\rm esc}$ not only decides the amplitude of H I ionizing UVB but also plays an important role to infer the amount of He II in the IGM. Higher values of $f_{\rm esc}$ suppress the intensity of He II ionizing UVB more. We show that this effect can naturally explain the observed rapid increase in He II Ly-α effective optical depths at $z \sim 2.7$, that was inferred as a signature of the completion of He II reionization. We find that the mean free path of He II ionizing photons decreases rapidly with increasing $f_{\rm esc}$. This study emphasizes the importance of the careful observations and models of $f_{\rm esc}$ even to study the He II re-ionization and fluctuations in the UVB.

- **Star formation and dust attenuation history**
  To estimate the contribution from galaxies to the EBL, we need the star formation and dust attenuation history. The star formation history derived using galaxy luminosity functions is known to be degenerate with the dust attenuation suffered by photons emitted by stars in the galaxies. We present a novel method that lifts this degeneracy and provides a self-consistent star formation and dust attenuation history for an assumed extinction curve. We use five well known extinction curves and find that the extinction curve observed for the Large Magellanic Cloud supershell provides star formation and dust attenuation history consistent with several observations. We use this dust attenuation to estimate the amount of radiation absorbed by dust in galaxies at UV and optical wavelengths. This information allows us to estimate the galaxy emissivity up to FIR wavelengths.

- **The EBL and propagation of high energy γ-rays**
  We model the EBL from 0.1 to 1000 μm using the estimated galaxy emissivity from UV to FIR wavelengths. We compare it with the local measurements and other theoretical models. These EBL photons annihilate the high energy γ-rays in to relativistic electron positron pairs upon collision. This pair-production mechanism destroys the high energy γ-rays travelling from source to the Earth. This provides an effective optical depth for γ-rays, and the magnitude of that depends on the spectrum of EBL. We estimate this optical depth at different energies of the γ-rays emitted from different redshifts and compare it with various observations and theoretical estimates. We find a good agreement with the measurements of it from the Fermi Large Area Telescope.

- **QSO emissivity and the resolution of Photon Underproduction Crisis**
  Spectrum of the UVB decides the hydrogen photoionization rate ($\Gamma_{\rm HI}$). The $\Gamma_{\rm HI}$ can be inferred

using Ly-α forest lines seen in the QSO spectra. Using such a measurement, a recent study claimed that the $\Gamma_{\rm HI}$ inferred at low-z ($z < 0.4$) is too high to be produced by standard sources (i.e ., QSOs and galaxies) and one may need non-standard sources of UVB such as dark matter decay. This result was called as 'photon underproduction crisis'. We investigated this claim using our UVB code. Using the recently reported QSO luminosity functions, we update the QSO contribution to UVB and find that it is a factor of $\sim$2 higher than the previous estimates. Using this in conjunction with our derived star formation history, we show that there is no real 'photon underproduction crisis' and the inferred high values of $\Gamma_{\rm HI}$ at low-z can be easily produced by QSOs and galaxies.

- **Redshift evolution of $f_{\rm esc}$**
  Having updated the star formation history and QSO contribution to the UVB, we estimate the $f_{\rm esc}(z)$ at all redshifts that is required to reproduce the $\Gamma_{\rm HI}(z)$ measurements and to reionize the Universe. We find a steep rise in $f_{\rm esc}$, of at least a factor of 3, is required over a very short time from $z = 3.5$ to 5.5. We show that, this requirement of a steep rise can be relaxed if we consider a recently found large number density of faint QSOs at $z > 4$. In addition, a simple extrapolation of the contribution of such QSOs to high-z suggests that QSOs alone can reionize the Universe. This implies, at $z > 3.5$, that either the properties of galaxies should evolve rapidly to increase the $f_{\rm esc}$ or most of the low mass galaxies should host massive blackholes and sustain accretion over a prolonged period. These results motivate a careful investigation of predictions of these alternate scenarios that can be distinguished using future observations.

The organization of this thesis is as follows:

- **Chapter 1** provides a brief introduction to the IGM and the cosmic background radiation. This is followed by a detailed introduction to the theoretical modelling of cosmic background radiation with gas distribution in the IGM and source emissivities. Most of the important equations and procedures that we will require in subsequent chapters are described here. This is followed by a brief introduction to the observational methods and existing observations of UVB and EBL. Then we introduce the recent models of UVB and provide the motivation for the thesis.

- In **Chapter 2**, we briefly describe the radiative transfer code developed by us to estimate the cosmic background radiation. We use this code to study the effect of $f_{\rm esc}$ on the UVB at $2 < z < 4$. We explain the method to infer the amount of Helium in the IGM from the observed distribution of H I. We study the changes in the UVB spectrum for different values of $f_{\rm esc}$ and its implications for He II reionization.

- In **Chapter 3**, we present our novel method that lifts the degeneracy between star formation and dust attenuation history. We discuss the results of it and provide a detailed comparison with the previous estimates. We explain the method to obtain the FIR emissivity from galaxies and discuss the results. In the end, we quantify the uncertainties arising in the derived star formation and dust attenuation histories due to assumed average properties of the galaxies.

- In **Chapter 4**, we use the galaxy emissivity obtained in the previous chapter to estimate the EBL. We provide a comparison of it with the local EBL measurements and various theoretical estimates. We also estimate the attenuation suffered by high energy γ-rays due to the EBL and compare the predictions with measurements.

- In **Chapter 5**, we update the QSO emissivity using recent measurements of QSO luminosity functions and provide a comparison of the old and recent luminosity functions measurements and corresponding emissivities. We discuss the problem of photon underproduction crisis in obtaining the low-z $\Gamma_{\rm HI}$, and provide the solution to it using this updated QSO emissivity and the star formation history obtained in the previous chapter.

- In **Chapter 6**, we use the updated QSO emissivity and star formation history from previous chapters and estimate the $f_{\rm esc}$ required to reionize the universe and to maintain the observed ionization state of the IGM. We discuss the results of it along with the implications of higher QSO emissivity at $z > 4$ for the trend in the derived $f_{\rm esc}$ with z and for the H I reionization.

- **Chapter 7** presents preliminary results of our new UVB model developed using results of the previous chapters. Then we highlight the main results of the thesis. This is followed by the future directions to further improve our model of cosmic background radiation and to address various issues.

Nagendra Kumar

MODELLING SPECTRAL TIMING BEHAVIOUR OF COMPACT OBJECTS

Close binary system, with short periods of the order of hours or days, had been observed in the early 1950s as bright optical sources. In the early 1970s, the first X-ray bright close binary system was discovered. In a close binary system, one star is a compact object and the other one is a main sequence star. The optical bright binary systems have white dwarf as the compact object and are termed as 'cataclysmic variables'. The X-ray binaries on the other hand, contain either a neutron star (NS) or a black hole. The X-ray binaries are divided into two classes: low-mass X-ray binaries (LMXBs) and high-mass X-ray binaries (HMXBs). The HMXBs are systems with an O or B star as the companion, while the LMXBs have a K or M star as a companion. The main focus of this thesis is on NS LMXBs systems, in which the neutron star accretes matter via Roche lobe overflow from the companion star by forming an accretion disk. The X-rays are usually emitted from the inner accretion disk and/or the boundary layer near to the neutron star surface.

LMXBs can either be transient sources (which undergo episodic X-ray outbursts) or can be persistent bright sources. However, all LMXBs are variable in X-rays. NS LMXBs are divided in to Z and Atoll sources based on the shape they track in their colour-colour diagram (CD) and from the different timing behaviour that correlates with their position on these tracks. A colour-colour diagram is a map of the ‘soft colour’ vs. ’hard colour’ as a function of time, where the soft colour is the ratio between the X-ray counts in a soft band (for e.g., the ratio of counts in 3.5-6 to 2-3.5 keV), while the hard colour is similarly defined in the hard band (for e.g., the ratio of the counts in 9.7-16 to 6–9.7 keV). Z sources trace through the colour-colour plot on time scales of hours to days and do not show hysteresis. The transient Atoll source motion in the CD is lower with time scales of the order of days to months when they are in the hard part of the CD, and move faster when they are in the softer part and they show hysteresis.

The X-ray spectra of LMXBs reveal that there should be a ‘corona’ or a hot electron gas cloud above the inner disk or NS surface, which can Comptonize the disk radiation. NS LMXBs generally have three spectral states, high luminous “soft state”, low luminous “hard state”, and intermediate state or “transitional state”. The soft/high intensity state is dominated by thermal emission, or a black body like radiation, which may be the disk radiation. In the low hard state, the spectrum is dominated by a power-law emission and the most acceptable radiative mechanism, for it is the thermal Comptonization process. In general, the X-ray spectrum of NS LMXBs are described by three components: a thermal component, a disk emission line (prominently the Fe Kα line), and a non-thermal component which is attributed to Comptonization. The disk emission line is generated when the disk is irradiated by the hard X-ray source, which may be from the NS surface or from the corona. There are two degenerate spectral models for NS LMXBs, the “hot seed photon model” and the “cold seed photon model”. In the hot seed photon model, the thermal component is interpreted to be multi-colour disk black-body (MCD) emission attributed to the accretion disk, while the seed photons for Comptonized component are emitted from close to the NS surface or the boundary layer. In the cold seed photon model, the thermal component originates from the boundary layer and is described by a single-temperature black-body, while the seed photons for Comptonization are emitted from the accretion disk.

LMXBs X-ray flux are highly variable and sometimes show milli-second variability. In 1993, milli-second variability was discovered by the Rossi X-Ray Timing Explorer (*RXTE*) observations of X-ray binaries. Rapid variability is generally studied by computing the Fourier power spectrum ($P_\nu(\nu)$, where ν is the Fourier frequency, ranging from mHz to 100kHz) of the X-ray flux time series. In the power spectrum, the broad structures are called ‘noise’, while narrow features are called quasi-periodic oscillations (QPO). The milli-second variability in the frequency domain are termed as kHz QPOs. Two simultaneous kHz QPO (upper and lower) are observed often in these systems and their frequency separations ($\delta\nu$) are generally not constant and range from $\sim$ 200 to $\sim$ 400 Hz. In Atoll sources, the lower kHz QPO has generally a larger quality factor Q, (which is the ratio of the QPO frequency to the full width at half maximum) than upper kHz one. The kHz QPOs exhibit complex variation with intensity in long time scales but are positively correlated on short time scales of hours. The kHz QPOs occur during soft to hard spectral state transitions, that is they occur in the intermediate state. In other words, the kHz QPOs occur at definite positions in the CD.

In a Schwarzschild geometry, the orbital frequency corresponding to the innermost stable circular orbit (ISCO) of radius $6GM/c^2$ is $\approx 1566/m_{1.4}$ Hz; where $m_{1.4}$ is the mass of the compact object in units of $1.4M_\odot$. This frequency is anticipated to be the maximum possible frequency for a non-rotating neutron star system. The maximum observed kHz QPO frequency is around 1200 Hz in NS LMXBs. There are several models to interpret one of the twin kHz QPOs as the Keplerian frequency at a particular radius. For example, in the sonic-point model, the upper kHz QPO frequency is interpreted as the Keplerian frequency at the sonic radius, while the lower kHz QPO is generated by the modulation of the upper QPO with the neutron star spin frequency. There have also been attempts to understand these QPOs as global oscillation in the accretion disk due to hydrodynamic, or magneto-hydrodynamic (MHD) instabilities or waves. These models for the kHz QPOs only give its physical interpretation regarding where and how they originate, but they do not explain the connection between X-ray spectral components and kHz QPOs which is found in all NS LMXBs. Especially the association of kHz QPO with the primary thermal Comptonization component which typically dominants the spectra. This association is additionally seen in terms of the amplitude and phase angle of QPO with photon energy. The fractional root mean square (r.m.s.) amplitude of the kHz QPOs increases with photon energy. The phase angle variations are usually studied in terms of the phase difference ($\Delta\phi$) or time lag ($\Delta\phi/2\pi\nu$) of an energy bin with respect to one reference energy bin. For the lower kHz QPOs, the time lag is found to be 'soft', i.e., the soft photon arrives later in comparison to the hard ones and this is confirmed statistically by analysis of large archival *RXTE* data set for at least three NS LMXBs.

The energy dependence of the kHz QPOs can be explained in the context of the thermal Comptonization (TC) model. In this model, the driving mechanism for the QPO is the coherent oscillation of either the seed-photon source temperature, T_b, or the corona temperature, T_e, or a linear combination of both. The TC model has free parameters like the temperature oscillation amplitude ($\Delta T_e, \Delta T_b$), and the medium geometrical parameters (i.e., size), which can be obtained by fitting the energy dependence of the r.m.s. and phase lag.

The objective of this thesis is to study the energy dependence of the r.m.s. and phase lag of kHz QPO using the thermal Comptonization model, in order to estimate the size and geometry of these sources. The first Chapter of the thesis gives an overview of spectral and timing observation of NS LMXBs and briefly discuss the accretion disk physics.

In Chapter 2, we develop a thermal Comptonization model to study the energy dependent photon variability from a thermal Comptonizing plasma that is oscillating at kHz frequencies. In particular, we solve the linearized time dependent Kompaneets equation and consider the oscillatory perturbation to be either in the soft photon source or in the heating rate of the plasma. For each case, we self consistently consider the energy balance of the plasma and the soft photon source. The model incorporates the possibility of a fraction of the Comptonized photons impinging back into the soft photon source. We find that when the oscillation is due to the soft photon source, the variation of the fractional root mean square (r.m.s.) is nearly constant with energy and the time-lags are hard. However, for the case when the oscillation is due to variation in the heating rate of the corona, and when a significant fraction η of the photons impinge back into the soft photon source, the r.m.s. increases with energy and the time-lags are soft. As an example, we have compared the results with the ~ 850 Hz oscillation observed on March 3, 1996 for 4U 1608-52 and show that both the observed soft time-lags as well as the r.m.s. versus energy can be well described by such a model, where the size of the Comptonizing plasma is ~ 1 km. Thus, we conclude that modelling of the time-lags as due to Comptonization delays, can provide tight constraints on the size and geometry of the system.

Having established that the thermal Comptonization model can broadly explain the r.m.s. and time-lag for kHz QPOs, in Chapter 3, we undertake a more detailed study. The time averaged spectra of NS LMXB can be fitted by two degenerate spectral models, which are called the "cold" and "hot" seed models. We tested the March 3, 1996 for 4U 1608-52 using both models and found that both of them can explain the r.m.s. and time-lag. However, the size inferred from the hot seed spectral model is $\sim$ 0.5 km while for the cold seed one it is $\sim$ 2 kms. Other observations of the source do not have the same data quality, but for some observations time-lag between two energy bins can be obtained. Alternatively, averaging of several observations provide time-lags in a few energy bands. We compare these results with the model and infer similar sizes and constraints. The inferred size of the system increases with QPO frequency for the "hot" seed spectral model, but no such trend can be discerned for the "cold" seed model. For the high quality observation, the r.m.s. versus energy for the upper kHz QPO suggests that the driving oscillation is the same as the lower one, i.e., it seems to be driven by variations in the coronal heating rate. However, the timelag has been reported to be hard for the upper kHz QPO. While the statistics of this result is less certain than the lower kHz QPOs, we note that if indeed the time-lag for the upper kHz QPO is hard, that would be a serious challenge. Finally, we also obtain similar results for the kHz QPOs in the persistent source 4U 1636-53 and hence generalize the results to other kinds of NS LMXBs.

The results obtained in the previous chapters require a certain fraction of the Comptonized photons to impinge back into the seed photon source, which has been discussed in Chapter 4. This was taken as a parameter η_e which was constrained based on the observed time-lags. However, this fraction depends naturally on the geometry of the system and hence should be computed for different geometries. Since this involves, tracing photons as the scatter in space, a Monte Carlo (MC) method is required. We have developed such a MC scheme for the thermal Comptonization process. The MC results were verified in terms of scattering number distribution and the resultant spectra, which were found to match well with analytical results. We then computed the fraction η_e. Three geometries were considered: (i) where the corona is a spherical shell covering the input source along with the possibility that there is a gap between the two, i.e., a hollow shell, (ii) where the corona is in the form of a boundary layer and (iii) where the corona exists above the accretion disk. We find that the η_e obtained from these geometries roughly correspond to the constraints obtained in the previous chapters for the first two geometries.

The conclusions and inferences of our studies are summarized in the final Chapter 5 which includes possible future work.

Suvodip Mukherjee

SEEKING PHYSICS BEYOND THE ISOTROPIC COSMOLOGICAL MODEL

Unprecedented quality of measurements of the cosmic microwave background (CMB) temperature and polarization field by several missions over the past few decades has significantly improved our understanding of the universe. The measured temperature anisotropy by WMAP and Planck is well explained by the minimal 6 parameter spatially flat, cold dark matter with cosmological constant ΛCDM model. However, these missions also revealed an unforeseen signal that violates one of the fundamental pillars of cosmology, viz., the assumed statistical isotropy (SI) of the cosmos. This isotropy violating signal in the CMB temperature field, known as cosmic hemispherical asymmetry (CHA), was detected at slightly more than 3σ significance in the clean CMB maps from WMAP as well as Planck. It implies that the hemisphere centered at the direction, $\hat{p} = (l, b) = (228°, -18°)$ in Galactic coordinates, exhibits 14% enhanced variance in the temperature fluctuations, and correspondingly suppressed variance in the fluctuations in the opposite hemisphere. In this Ph.D. thesis, we address this particular problem of the standard cosmological model at the interface of both theoretical and numerical modelling. A brief summary of the findings reported in the thesis is given below.

In Chapters 1 and 2, we introduce the topic, and make a strong background, and build up the motivation for the study.

In Chapter 3, we review the scale-dependent features like power suppression in the angular power spectrum and CHA in the temperature field of CMB at large angular scales, hinting at the possible departure from the ΛCDM model persist in the CMB data. We present a physical mechanism linked to possible initial inhomogeneities in the inflationary scalar field that could generate CHA in both scalar and tensor sector within the framework of a single field inflationary model with an initial fast-roll phase. The modulation amplitude of CHA in both scalar and tensor perturbations is related and depend on the initial shape of the inflaton potential. By using the observed value of CHA and obeying the isotropy of the temperature field of CMB, we obtain a theoretical upper bound on the amplitude of CHA for tensor perturbations within the framework of single field initial fast roll inflation models.

The origin of CHA in temperature field of CMB from scalar perturbations gives rise to a general curiosity to investigate other possible windows which can estimate the CHA, which is present in the scalar sector. In Chapter 4, we explore a new window, which can shed light on the origin of this anomaly. We demonstrate that weak lensing of the CMB due to SI violated scalar perturbations produce correspondingly an SI violation in the B modes of CMB polarization at smaller angular scales. Measurability of this phenomenon depends on the scales and corresponding angular multipole (l range) over which power asymmetry is present. This effect can also place an independent bound on the spatial range of scales over which hemispherical asymmetry is present in the scalar sector.

The other known source of dipolar asymmetry in the statistics of CMB fluctuations is due to the local motion (v = 369 km/s) of the barycentre of Sun with respect to the CMB rest frame. In Chapter 5, we investigate the relativistic corrections on CMB temperature and polarization field due to our local motion, parameterised by $\beta = v/c$ and also investigate its measurability from future CMB missions. In the frame of a moving observer, the CMB fluctuation exhibits the violation of SI. The Lorentz transformation of the polarization field leads to the aberration in the direction of incoming photons and also modulation of the Stokes parameters, which results in mixing of power between different CMB multipoles. We show that at leading order of β, the effect on the off-diagonal terms could provide a measurable signature from CMB temperature and polarization.

The presence of CHA in the CMB temperature makes it essential to understand the statistical properties of this effect and also to understand the effect of this on cosmology. Beyond CHA, there are also other known SI violation effects arising from Doppler boost, asymmetric beam, masking, etc. Statistical studies of SI violation effect require non-SI (nSI) Gaussian realizations of CMB field. The nSI Gaussian field leads to non-zero off-diagonal terms in the Spherical Harmonics space covariance matrix encoded in the coefficients of the Bipolar Spherical Harmonics (BipoSH) representation. In Chapter 6, we present an effective numerical algorithm, Code for Non-Isotropic Gaussian Sky (CoNIGS), which is developed to generate nSI realizations of Gaussian CMB temperature field of any resolution with specific cases of SI violation. Realizations of nSI CMB temperature field are obtained for a few cases, which include quadrupolar (L=2) BipoSH measurements by WMAP, CHA and Doppler boost.

With the ability to produce nSI simulations using CoNIGS, we can address several interesting questions related to an SI violated sky. One of the questions of primary interest is to understand the implications of SI violation on cosmological parameters. In Chapter 7, we investigate the effect of CHA on cosmological parameters using nSI Gaussian random simulations for different kinds of modulation strength. Our analysis shows that A_s and n_s are the most susceptible parameters to acquire position dependence across the sky for the kind of isotropy breaking phenomena under study. As expected, we find that maximum variation arises for the case of scale independent modulation of CMB anisotropies. Further, the scale dependent modulation profile as seen in Planck data could lead to only 1.25σ deviation in A_s, in comparison to its estimate from isotropic CMB sky.

The scale dependent origin of the asymmetry, which is observed in the temperature field of CMB can originate from scalar perturbation as well as from tensors in general. In Chapter 8, we propose a phenomenological model with mixed modulation field for scalar and tensor perturbations, which affect the temperature fluctuations at large angular scales. Hence, this model is a possible route to explain the scale-dependent nature of the modulation field. The salient prediction of this model is the direction dependent tensor to scalar ratio, which results in anisotropic Stochastic Gravitational Wave Background (SGWB). Using the Planck SMICA map, we constraint the modulation amplitude, which is possible in the tensor perturbations, for different values of the tensor to scalar ratio r. We also obtain the maximum modulation amplitude in tensor perturbations, which is measurable from the B-mode polarization map of future missions.

AstroSat Activities at IUCAA

Activities at IUCAA related to the AstroSat Mission includes the running of two key services: The AstroSat Science Support Cell, and the Cadmium Zinc Telluride Payload Operation Centre.

AstroSat Science Support Cell

After the successful launch of AstroSat in September 2015, the first Indian multi-wavelength astronomy satellite, it has been producing unprecedented high quality data of the Universe. It is a proposal-driven, observatory class mission, with a large fraction of the time open to national users outside of the payload instrument teams. With five specialized instruments on board, AstroSat's mission is to observe a wide variety of astronomical sources, such as star forming region, violent explosions like gamma-ray bursts, and high energy emission from systems harbouring black holes and neutron stars. In its ten year life time, it is expected that AstroSat will produce more than 500 unique observations of different astrophysical sources, each having an independent scientific objective.

These observations will provide a unique opportunity to a large number of scientists from all over the country to do internationally appreciated, front-line research using a state-of-the-art indigenous national facility. The AstroSat experience would enable these scientists, most of whom would be young Ph.D. students and university teachers, to become members of a well spread, vibrant and confident Indian Astronomy community, who would lay the foundation for the next generation of space based scientific research. Indeed, it is imperative that a large Indian community utilizes AstroSat data, for the mission to fulfil its primary goal as a national facility that will promote astronomy research in the country.

There is the potential in a number of universities and institutes in the country to attract Ph.D. students, who are excited by AstroSat science. Moreover, there are also young teachers in universities and colleges, who would be interested in using AstroSat to do front-line research. However, since this is the first time such an observatory is available in India, these young scientists would necessarily require initiation, training and mentoring, if they have to optimally utilize the AstroSat facilities.

To address these requirements, the Indian Space Research Organization (ISRO) and IUCAA have established the AstroSat Science Support Cell (ASSC). The cell is hosted at IUCAA, and started its operations in May 2016, and has been formally dedicated to the nation by the Chairman, ISRO when AstroSat completed one year of operations on September 29, 2016.

ASSC Personnel and Hardware

Members of the CZTI POC and ASSC: Bhagyashri Dighole, Saraswathi Lakumarpu, Pradnya Bhoye, Anjali Rao, Kanak Saha, Dipankar Bhattacharya, Ranjeev Misra, Ajay Vibhute and Gulab Dewangan

The ASSC has been equipped with the state-of-the-art computing and data storage facilities. There are six, all-in-one desktop computers, two high end laptops and a Dell workstation 7910, equipped with 8TB disk space, 250GB RAM and 14 Intel Xeon Processors E5-2690 CPUs. The workstation is equipped with the pipeline software and calibration database for AstroSat instruments and other major X-ray astronomy software. The ASSC has hired one post-doctoral fellow and two software engineers.

ASSC Web Portal and Software Development

The ASSC web portal maintains up-to-date information and online tools to help users propose for AstroSat observations and to analyze the data. For proposers, it has the announcements of opportunities, proposal templates, online tools, such as exposure time and visibility calculators, data simulation codes and necessary documents such as the proposers' guide and AstroSat Handbook. For data analyzers, the latest available pipelines for all four instruments are maintained including sample data, which allows the user to actually try out the analysis. The results of the analysis of the sample data are made available allowing the new user to evaluate whether his/her analysis matches with the standard ones or not. Additional important software, such as the AstroSat orbit file generator, the Barycentric correction code and the AstroSat time converter, have been developed in-house at the ASSC, and are made available through the portal. ASSC has also developed advanced resources like software to compute frequency and energy dependent time lag from LAXPC data. The portal has links to other relevant resources, such as the GHATS timing package. The portal presents recent updates and news as well as the currently available AstroSat's schedule of observations.

The AstroSat Proposal Processing System (APPS)

AstroSat is a multi-wavelength astrophysics observatory for a large scientific community. The five payloads onboard have different scientific capabilities and technical constraints. The peer-reviewed, scientific proposal-driven operation is an intricate and a challenging process. To facilitate the proposal-driven operation of the AstroSat mission, a web-based proposal processing software known as the “AstroSat Proposal Processing System" (APPS) has been designed and developed by IUCAA in collaboration with Persistent Systems Limited (PSL), Pune.

APPS assists scientists in proposal preparation, submission, scientific and technical review and selection process. It caters to different types of users, including the general or guest observers, payload operation centre team members, payload scientists and proposal reviewers. It can validate submitted proposals including syntax checking, parameter ranges and proposal completeness, thus, allowing proposers to detect errors. APPS provides a complete and flexible interface for the users to specify instrument configurations appropriate to their science requirements. It also allows proposers to revise proposals with changes in requested observing time, number of targets to instrument configuration as per recommendations of the technical and/or scientific peer-review processes. APPS also extracts important proposal information including the instrument configuration, which is used for mission planning and scheduling of observations.

APPS is currently deployed at the Indian Space Science Data Centre (ISSDC), ISRO, Bengaluru. It has been successfully used for proposal preparation, submission and selection for observations in the (i) Performance verification (PV) phase in the first six month of AstroSat operations, (ii) First, second and third Guaranteed Time (GT) cycles, (iii) First and second Announcement of Opportunity (AO) cycles, Target of Opportunity and Calibration proposals. IUCAA has played a crucial role in quick fix of bugs and security issues, addition of new features as per the requirement, documentation, and feature enhancement. IUCAA has also provided time-critical support on administrative activities, including proposal cycle creation, setting instrument configuration, handling proposal review during the GT cycle and revision of proposals, verifying and fixing issues with the mission control and proposals database (MCAP), which is used for mission planning, scheduling of observation and command generation. IUCAA has also provided support to the proposers including those from payload science teams on GT proposals, payload operation centres on CAL proposals, and guest observers on AO proposals. Further, IUCAA has prepared the AstroSat Proposers guide, and proposal preparation tools, such as the multi-instrument spectral simulator, AstroSat PIMMS, etc. All the proposal preparation tools, instrument responses and background files as well as documents have been made available at the ASSC website.

Workshops and Meetings Arranged by ASSC

Kiran Kumar, Chairman, ISRO; Tapan Mishra, Director, PRL; and IUCAA members celebrating one year of AstroSat in a meeting held at IUCAA to commemorate the event

One Year of AstroSat: A Science Meet to Commemorate One Year of AstroSat in Orbit

On September 28, 2016, AstroSat completed its first year of successful operation. To celebrate the occasion, an one day meeting was organised at IUCAA, on Thursday, September 29, 2016, to highlight the technical and scientific achievements of the AstroSat. In the morning, Kiran Kumar (Chairman, ISRO), Tapan Mishra (Director, PRL), and S. Seetha (AstoSat PI) visited the AstroSat Science Support Cell, where they were shown how the cell has been equipped to analyze the data from different AstroSat payloads, and the working of the AstroSat Proposal Processing System (APPS). They also visited the IUCAA laboratory and were shown the model for the Solar Ultraviolet Imaging Telescope (SUIT) instrument, which is scheduled to fly on onboard the Aditya - L1 mission. The meeting started with a welcome by the IUCAA Director and an introduction by P.C. Agrawal. The Chairman, ISRO delivered the keynote address, and dedicated the Astrosat Science Support Cell (http://astrosat-ssc.iucaa.in/) hosted at IUCAA. This was followed by an official release of AstroSat outreach posters. The first scientific results and the future scope of the satellite was presented by the payload managers of the different instruments and in the afternoon, there was a panel discussion on the future of Indian Space Astronomy. The meeting was attended by several dignitaries from ISRO and other institutes from all over the country, who have been involved with AstroSat.

Meeting on AstroSat AO Proposal Submission: Guidelines and Technical Issues

The first Announcement of Opportunity (AO - 1) for Indian Scientists to propose for AstroSat observations was announced by ISRO with a deadline for submission on July 29, 2016. In this context, the ASSC held its inaugural meeting on AstroSat AO Proposal Submission: Guidelines and Technical Issues, during July 13 - 14, 2016 at IUCAA. The meeting had overview talks on AstroSat, and its payloads, with emphasis on the results obtained during the performance verification phase.

A key element of the workshop was a set of extensive demonstration sessions, where the participants were shown in a step-by-step manner how to propose for AstroSat observations, and in particular, the choice of how to configure each instrument in order to optimize the science output. There were also discussion forums, where the participants raised queries and concerns, which were addressed by the experts. Some of the key speakers were S. Seetha (ISRO), J. S. Yadav (TIFR), K. P. Singh (TIFR), A. R. Rao (TIFR), S. N. Tandon (IUCAA, and IIA), S K. Ghosh (NCRA), D. Bhattacharya (IUCAA), and G. C. Dewangan (IUCAA).

Projects in X-ray Astronomy

In collaboration with the Association of Physics Teachers (APT), Kerala, and Providence College, a three day workshop was help in Kozikhode, to inform teachers and students of the region about AstroSat and the potential to use AstroSat data for both research and training in the form of projects at the M.Sc. level. More than 30 participants attended the workshop, and were given introductory lectures on X-ray astronomy and AstroSat instruments. Hands-on-sessions were also arranged, where the participants analyzed sample AstroSat LAXPC data.

Participants of the Meeting on AstroSat AO Proposal Submission

Workshop on Data Analysis and LAXPC Science

A workshop on Data Analysis and LAXPC Science, to inform and train young astronomers about LAXPC data analysis, was undertaken at TIFR, during January 18 - 21, 2017. About 30 scientists, consisting of Ph.D. students, post-docs, and young faculty members from all over the country participated in this workshop. The details and nuances of the complex analysis were shown during hands-on sessions, where the participants analyzed sample data from the LAXPC. The sessions were conducted by members of the LAXPC Science team and ASSC personnel.

ASSC members conducting LAXPC analysis session at the workshop on "Data Analysis and LAXPC Science", TIFR.

CZTI Payload Operation Centre

The Cadmium Zinc Telluride Imager (CZTI) is one of the five science payloads aboard AstroSat. The CZTI Payload Operation Centre (POC) hosted by IUCAA examines all the data received from this payload by the ground station and generates science products from them. The POC is also tasked with monitoring the health of the payload, carrying out periodic calibrations, commanding the payload as and when needed as well as the development and maintenance of the payload data analysis pipeline software and calibration database.

Ever since the switch on of the CZTI payload on October 6, 2015, the POC has worked non-stop round the clock to fulfil its designated functions and to provide CZTI data products to AstroSat archives for all users. CZTI POC has achieved the quickest turn-around time for data products among all of the AstroSat payloads, and was also the first to release fully functional analysis software for users. The POC has developed a large amount of custom software for automated, accurate and quick analysis of the CZTI data stream. The analysis activity continues to run on a 24 x 7 basis, with supervisory manual monitoring provided by the POC personnel. Young trainees are inducted for one-year internships in this activity and provided the necessary training in Space Astronomy data analysis and software development. Three trainees have successfully completed their one-year tenure, and one trainee is currently working at the POC alongside more experienced members.

Another activity that the POC is involved in is to look for high energy transient events in the CZTI data. The most common events of this variety are gamma ray bursts (GRB). During April 2016 – March 2017, the POC has detected and reported 69 GRB events from the CZTI data. The CZTI POC also looked for high energy transient events associated with Gravitational Wave detections, and have placed upper limits on their electromagnetic brightness.

The CZTI POC maintains a webpage http://astrosat.iucaa.in/czti/?q=grb, in which all the GRB detections by the CZTI are reported. It also maintains another publicly available page http://www.iucaa.in/~astrosat/czti_dqr/, that reports detailed logs and the data quality of all CZTI observations.

Computing Facility

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

The hardware and devices include 315 servers and desktops, 72 laptop computers, 60 printers and scanners, two large HPC systems and over a PetaByte of storage, in addition to diverse equipments deployed for an extensive, high throughput wired and wireless campus-wide network. The number of registered Wi-Fi devices is over 700, and e-mail accounts served by the computing facility amount to nearly 500.

Since August 2015, the e-mail addresses of IUCAA staff members, and since February 2016, that of IUCAA Associates are on IUCAA owned domain iucaa.in, and associates.iucaa.in, respectively. This is to ensure that regardless of ISP (Internet Service Provider) in use, the e-mail domain address will remain unchanged, and thus, withdrawing its dependency on the ISP.

IUCAA has been utilizing 1 Gbps from National Knowledge Network (NKN), the primary ISP (since January 2012) and 50 Mbps from TATA Communication, the secondary ISP (since October 2015) for internet usage. These two independent link paths have been configured to provide redundancy and robustness to the WAN connectivity.

In the year 2016-17, emphasis was given to identifying suitable: (i) Purpose built backup appliance (PBBA) through POC (Proof of Concept). Much awaited PBBA arrived, on March 24, 2017, in the form of Dell-EMC Data-Domain 6800, the back-end backup storage hardware and Net-worker, the front end backup software. The implementation part is still in progress. (ii) Technology upgrade for the Ruckus wireless solution was implemented in November 2010. Subsequently, in October 2016, POC was carried out and then 8 ZF7762 outdoor Access Points (Aps) were partially replaced with T301s APs. An order for the newest generation of APs, has been placed in March 2017 to revamp the entire Wi-Fi Network. The new proposed Wi-Fi network adheres to 802.11ac Wave 2, the newest version, which is built on first-generation 802.11ac technology, and delivers faster data rates and has the ability to communicate with four different clients simultaneously, instead of one at a time.

The Computer Centre continues to provide technical support to visitors, project students, and IUCAA associates, and carry out the day-to-day 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 for the RFP (Request for Proposal) tender document for IUCAA IT requirement to be purchased and oversee all purchase related procedure and follow up.
4. Maintenance of IT hardware in the campus including servers, desktops, mobile computing equipment, printers, etc.
5. Maintaining Zimbra email servers, and their day-to-day administration.
6. Configuration and maintenance of mirror sites hosted at IUCAA.
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 office as well as residential campus.
10. Configuration of Wi-Fi support to devices such as laptops, mobile devices for end users
11. Day-to-day administration of VmWare infrastructure and various servers catering to Administration such as AD, etc.
12. Maintenance of Video Conferencing equipment and end user support.
13. Comprehensive inventory management, asset management and tracking.
14. Procurement of SSL certificates and software for all the relevant web servers at IUCAA.
15. Management and software development for iOAS (integrated Office Automation System), Tally, TDS pack.
16. Designing web portals for various online applications.
17. End user service support to administrative staff, academic members, visitors and associates.
18. Infrastructure, management and coding support to IT intensive projects such as Virtual Observatory, AstroSat, LIGO, etc.
19. Procurement, installation and periodic upgradation of mathematical software such as Matlab, IDL, Mathematica meant for general IUCAA users and cluster users.
20. Hardware maintenance and general system administration of clusters in IUCAA in co-ordination with OEM.
21. Assisting estate department with data centre management.

High Performance Computing

The High Performance Computing facility houses some of the major IT assets of IUCAA.

Staff of the Computing Facility at IUCAA Datacentre. The High Performance Computing clusters are seen in the background.


IUCAA High Performance Computing clusters Perseus and Sarathi


Chiller plant assembly for IUCAA Data Centre

Power conditioning room for IUCAA Data Centre with UPS, battery banks and control panels

In March 2016, a new High Throughput Computing cluster named "Sarathi" was acquired and installed for the exclusive purpose of Gravitational Wave data analysis. This cluster, with 2520 CPU cores, has a peak CPU computing capacity of 90 Teraflops. Further, 10 Tesla K40 cards in this system provide an additional 45 Teraflops of GPU computing power. The total storage capacity attached to this system is over 300 Terabytes. To support the power and cooling requirements of this cluster, 80 KVA of additional UPS capacity and a 28 TR chiller was added to IUCAA's existing Data Centre infrastructure.

TMT Telescope Control System

The Thirty Metre Telescope (TMT), a segmented mirror telescope with a 30-metre filled aperture, will be the world's most advanced ground-based telescope operating at optical and infrared wavelengths. An international consortium of institutions in the USA, Canada, China, Japan and India is building the telescope. About 70% of India's contribution to the construction of TMT will be in-kind, and its share consists of both hardware and software. In software, India-TMT is responsible for delivering the Observatory Software (OSW) and Telescope Control System (TCS).

The TCS is responsible for the coordination and control of various telescope subsystems through various project phases: (i) The preliminary design, (ii) The final design, (iii) The code and test, (iv) The integration and test, and finally, (v) The assembly, integration and verification at the telescope site.

IUCAA, on behalf of India-TMT, is responsible for delivering the TCS to the TMT International Observatory (TIO). In April 2016, the contract for the first phase of the project was awarded to Oaces - Honeywell Automation India Limited.

The project started on April 5, 2016 with a kick-off meeting at IUCAA, and an Orientation Workshop was conducted during April 18 - 29, 2016 at TMT Project Office (PO), Pasadena, USA. As part of this workshop, the TCS team that consists of engineers and scientists from Honeywell, IUCAA and TMT Project Office also visited the Keck and Subaru Telescopes at Mauna Kea, Hawaii.

TMT TCS kick-off meeting at IUCAA (April 5, 2016)

TMT TCS team at the W. M. Keck Observatory, Mauna Kea, Hawaii.

In December 2016, the TCS team successfully completed this phase with the delivery of (i) design of the Hardware Control Daemon (HCD) that interfaces between the TCS and the Mount Control System (MCS) of the telescope, (ii) MCS simulator, (iii) design document for the interface between TCS and the telescope enclosure, and (iv) a detailed plan for all the subsequent project phases. The interface with the telescope enclosure was developed in collaboration with the engineers from the Canada-TMT team.

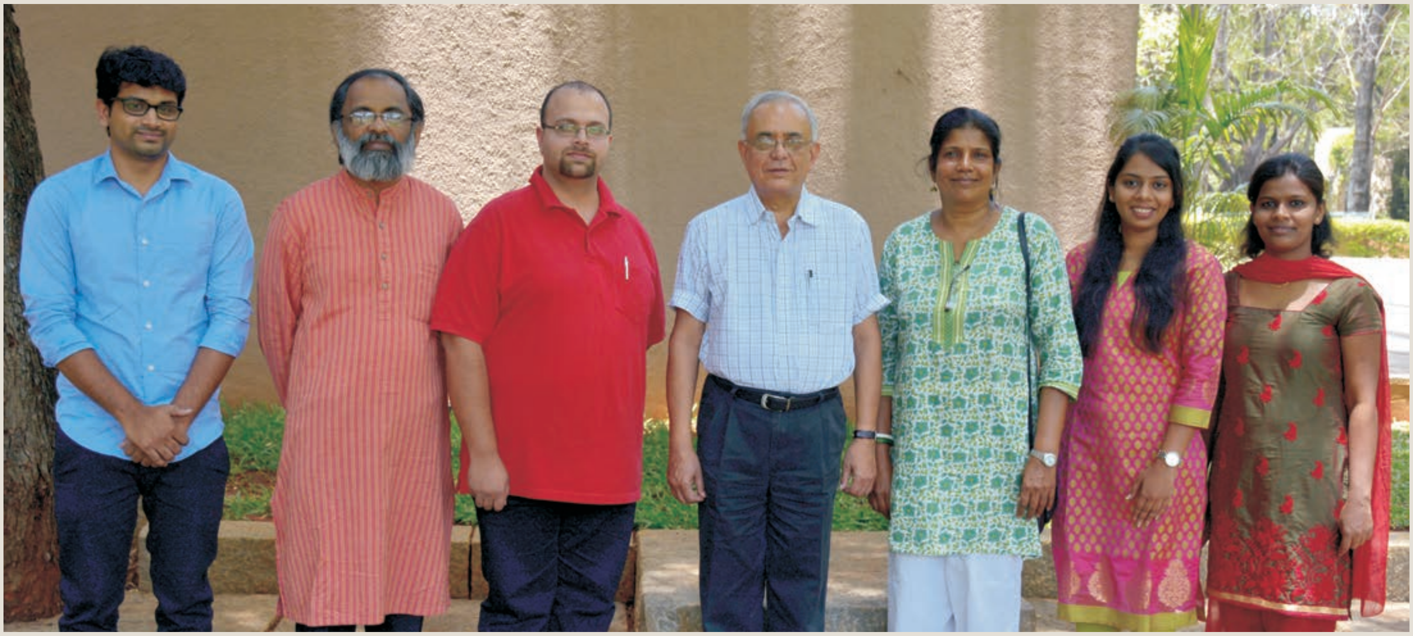
The successful completion of this phase is a crucial milestone towards delivering the full preliminary design of the TCS, which is arguably the most complex software system of the telescope. The full preliminary design phase (duration ~ 2 years) will start in May 2017.

Data Driven Initiatives in Astronomy and Biology

Astronomy is not the only discipline which is affected by the present data deluge. Big data, characterized by its high volume and its speed of generation is a problem that affects several other disciplines of science, such as climate, genomics, proteomics, etc. Handling these huge volumes of data is an important problem that needs to be addressed with haste. Experts in each domain, including those in the industry have been making individual efforts to address these problems. It would be particularly beneficial if experts from multiple disciplines, especially those related to scientific research, work together on these problems.

With this in mind, the National Knowledge Network (NKN) has funded a three year joint data management and mining project, to be led by Ajit Kembhavi and Dinakar Salunkhe (formerly the Director at the Regional Centre of Biotechnology, Faridabad, and at present, the Director at International Centre for Genetic Engineering and Biotechnology, Delhi). The key aims of these project include creation of data services for various data sets in domains of Astronomy and Biology, as well as to research data mining and management techniques for handling big data. It is hoped that techniques currently applied to specific domains will benefit experts in other domains as well.

A major project is already underway exploring best solutions for handling detailed metadata and versioning for the data produced at the AstroSat CZTI Payload Operations Centre located in IUCAA. A Virtual Observatory compliant service for 8+ billion image cut-outs obtained from the CRTS and served from IUCAA, has also been implemented. Planning is underway for projects exploring the application of astronomical image processing techniques in the domain of X-ray Diffraction Crystallography and Advanced Machine Learning techniques in the field of Mass Spectrometry of Proteins.



Library

During this year, the library has added 84 books along with major eBook resources as:

1. 160 Cambridge University Press
2. 124 Oxford University Press
3. Springer Physics and Astronomy collection 2016 and 2017
4. Springer Physics and Astronomy Book Archive of 6403
5. 146 World Scientific (print to electronic).

The library has an institutional subscription to 'Grammarly', an English language writing-enhancement platform. Also, complimentary access has been obtained to the selected e-resources (listed below), which have been set up by INFLIBNET, Gandhinagar, courtesy eShodh Sindhu Consortium for IUCAA.

The url is (http://www.inflibnet.ac.in/ess/eres.php?memID=115).

1. American Institute of Physics
2. American Physical Society
3. Emerald Univ Collection (133 titles)
4. Institute for Studies in Industrial Development (ISID) Database
5. Institute of Physics
6. JGate Plus (JCCC)
7. Springerlink
8. Taylor and Francis
9. Web of Science

Various other activities undertaken by the library are:

1. Extended access to subscribed e-resources to IUCAA Associates using the IUCAA LDAP authenticated email id and password. The Ezproxy Access and Authentication software facilitated this access.

2. Fulfilled 99 full-text article requests and references received from 39 academics (including students) through email/post/personal visits, and inter-library loan requests.

3. Recently deployed the Plex Media Server software for enabling streaming of HD videos of recorded lectures available with the library over the internet.

4. The archival contents of Khagol (The Quarterly Bulletin) and Annual Report are made available using Open Journal System (OJS). The library has undertaken the up-gradation of OJS along with the migration of the content on the new server. Further, to give an enhanced look to the content, the 'Flipping Book' utility software has been installed.

5. The library has been temporarily functioning from Akashganga Housing Colony since January 2017, on account of major refurbishment, however, will resume it's working from the mezzanine floor of the library from May 15, 2017.

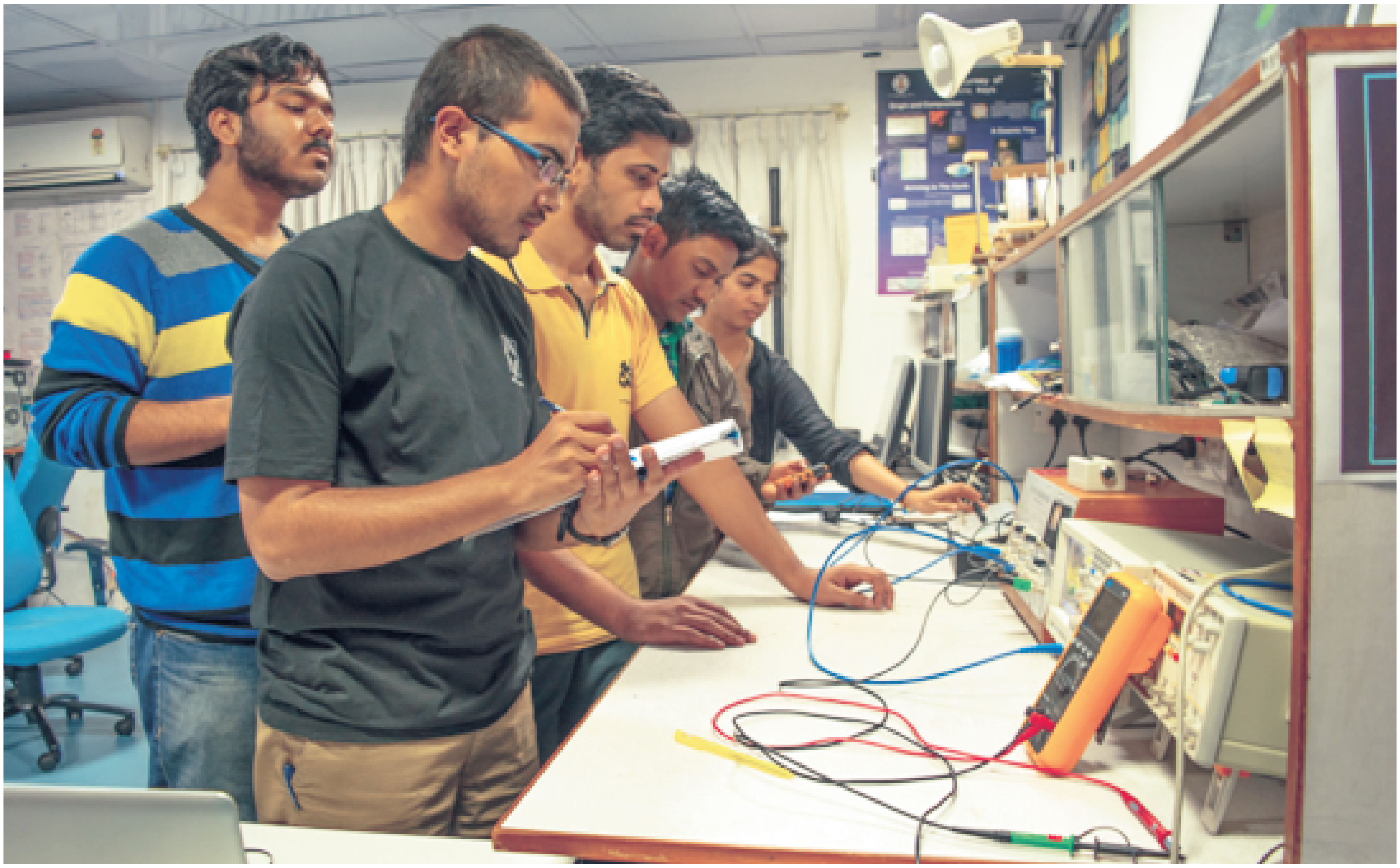
Radio Physics Laboratory

Radio Physics Laboratory (RPL) is active in experimental areas in astronomy, physics and engineering. Our aim has been to design and demonstrate important experiments related to astronomy in an innovative way, either for scientific purpose or for educating students, enthusiasts and general public. The areas being pursued range from cosmic ray detection to communication using LASERs. Apart from this, RPL is also active in public outreach. Public lectures and demonstrations are organized for students and enthusiasts. Radio Astronomy Winter School is conducted every year for under-graduate students to introduce them the field of radio astronomy. RPL has been active for over 10 years, and has conducted Radio Astronomy Winter School for 9 years, where over 300 bright students were selected and trained. Nearly 50 of them have gone on to join as research scholars in astronomy and astrophysics. Apart from this more than 40 M.Sc., M.E., and B.E./B.Tech. students have successfully completed their projects at RPL under the guidance of Joydeep Bagchi. Following are the details of experiments and activities carried out by RPL:

Experiments

Noise Fundamental Experiment

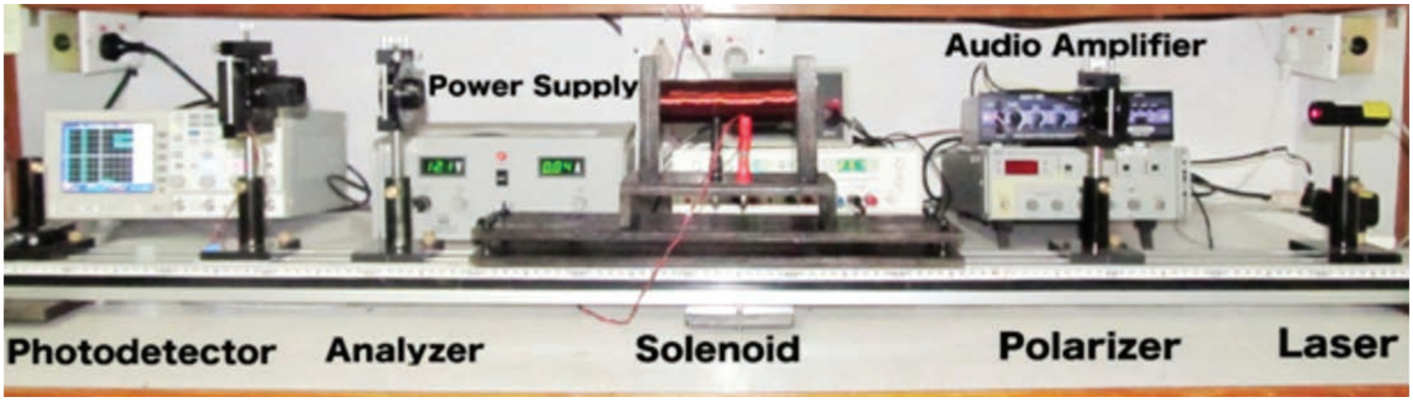
The Noise fundamental experiment is one of the most important tools to study the noise in any electronic system and instrument. The noise present in all electronic signals limits the sensitivity of many measurements. The thermal noise generated by a resistor at room temperature or the shot noise in diode and transistor can be studied by using this experiment. It is possible to see noise on the display of an oscilloscope and also play with it by changing parameters of noise, like temperature, bandwidth, etc. Importantly, Boltzman constant and charge of electron can also be measured using this experiment.



Faraday Rotation Experiment for Communication

The polarization of light is quite frequently observed in nature, and with other properties like amplitude, frequency and phase of an electromagnetic (EM) wave, it constitutes one of the most fundamental quantities, which completely describes it. In physics and optics, the polarization of light is studied through ”Faraday Rotation Effect” using optical materials like glass, crystals, chemicals, etc. Its analogue in radio waves is transmission of polarized wave in ferrites materials. The idea is to study the potential of fast polarization modulation for data communication, which is not much explored yet.

The study of polarization of light through Faraday Rotation Effect, rotation of plane of polarized wave when traveling through crystals placed inside solenoid; subjected to a strong axial magnetic field, can be a novel approach in communication. Experiment shows conversion of polarization-modulated light into intensity-modulated light, and phase shifted demodulated wave form with respect to input modulating signal. Insertion of properly matched and tuned circuit before coil and amplifier after demodulation leads to better reception of signal.

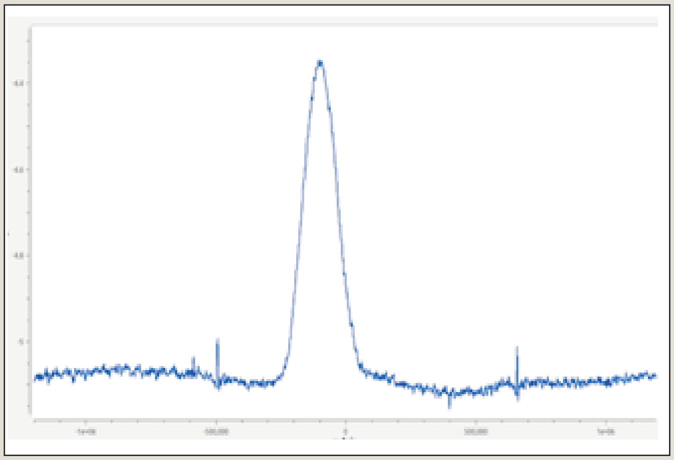


The laser will act as a carrier and the audio is given as a modulating signal to the solenoid, the audio signal modulated in the presence of Faraday material (TGG) and demodulated by converting polarization modulation into intensity modulation at the photo detector. The power requirement is very low as compared to the existing analog modulation techniques. The system is successfully working over the audio bandwidth.

Horn Antenna for 21 cm Hydrogen Line

The 21 cm Hydrogen line is a spectral line emitted by atomic Hydrogen. Since Hydrogen is the most abundant element in the universe, this makes the Hydrogen line a very important in radio astronomy. A horn antenna was designed for detecting this line from our galaxy.

The horn has enabled us to study hydrogen line profiles from the galaxy. The spiral structure of the galaxy can be estimated. It is also possible to estimate the rotation curve of the galaxy.



Hydrogen line from our galaxy

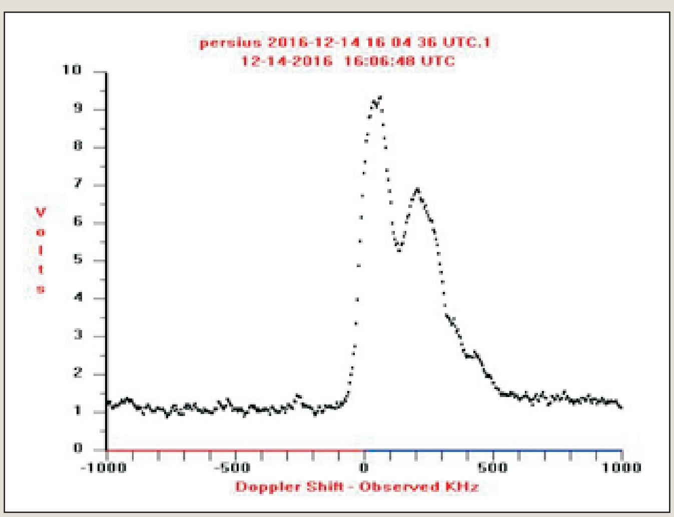
A major limitation of radio astronomy is noise, either man-made or naturally occurring. Hence, we require new techniques to reduce noise from our detector. The horn antenna is a high performance, high gain and low noise antenna, specially designed for detection of 21 cm Hydrogen line. The antenna is able to pick up radiation from the Hydrogen clouds in our galaxy, while suppressing terrestrial interferences due to the low side lobes of the antenna. The antenna is easy to handle and is superior to a parabolic dish in terms of noise performance.

The horn has enabled us to study hydrogen line profiles from the galaxy. The spiral structure of the galaxy can be estimated. It is also possible to estimate the rotation curve of the galaxy.

The antenna is a dual mode conical horn. It is easy to construct as compared to other antennas with similar noise performance. Software Defined Radio (SDR) receivers were used with great success. SDR is a new advancement in radio technology. The limitation of the conventional radios is its inability to configure the hardware. SDR can be configured to serve any purpose of the user. Such a receiver was implemented successfully for detection of Hydrogen line. Important techniques like Dicke switching were implemented with SDR. This has made the telescope low cost, and hence accessible to amateur radio enthusiasts. The antenna has proven to be very reliable. It will be used in M.Sc. practical in radio astronomy as well as in forthcoming Radio Astronomy Winter Schools. The antenna has also been used to demonstrate principles of radio astronomy to amateurs as well as for public outreach.

Metre Dish Antenna for Radio Astronomy

The newly installed 3 metre dish antenna at RPL is being used for experiments in radio astronomy. Experiments like detection of 21 cm Hydrogen line, and observation of solar activities are regularly carried out with this antenna. It has a control system, which enables one to point and track celestial objects. The antenna will be used in educational activities at RPL.



Hydrogen line from our galaxy

Cosmic Ray Muon Detector

The cosmic ray muon detector (CRMD) is a particle detector, which can detect and observe products of cosmic ray particles, which are created and accelerated by very violent mechanisms in the Universe. The CRMD at RPL is one of its kind, and was built in 2011 by bachelors' degree level students. It is the only detector of its type running in entire ASIA. The materials to build the detector were imported from Fermi Lab (USA).

This detector is used to take readings of constant muon flux and determine mean lifetime. It is quite a rich experiment as it enables students to not only study astroparticle physics, but also quite a lot about nuclear and particle physics in general. Mean muon lifetime also serves as a test for Einstein's special theory of relativity. Since 2012, the detector has been used for experiments in Savitribai Phule Pune University M.Sc. Astronomy and Astrophysics specialization course, as well in Radio Astronomy Winter Schools.

Other Experiments

Many small experiments are done in the lab, such as noise figure measurement of radio frequency amplifiers. Solar observations are taken at 10 GHz with a satellite TV dish antenna. This is a low cost and easily available radio telescope.

Science Day

Science day is an important event in IUCAA. It is the time of the year when IUCAA is open to general public all day along, and all the staff of IUCAA is involved in activities related to public outreach. The RPL has been demonstrating and explaining various astronomy related experiments over the years. This year, on February 28, 2017, we have presented the horn antenna designed for detection of atomic Hydrogen in our galaxy at 21 cm wavelength. A quite similar antenna was used to discover the Cosmic Microwave Background Radiation by Penzias and Wilson back in in 1960s. The antenna came in handy to explain the working of radio telescopes to the public. We also have demonstrated the recently installed 3 metre antenna at RPL. A live demonstration of Hydrogen line detection was presented. The Cosmic Ray Muon Detector was on display showing live detection of muon particles created by cosmic rays in upper atmosphere. We presented a simple and low cost radio telescope using a dish TV antenna. Posters on history of radio astronomy, activities of RPL and a video display of upcoming radio telescopes were also presented.

Astronomical Society of India (ASI) Meeting

Astronomical Society of India (ASI) Meeting is an annual event, which provides a platform for presenting and propagating research in the field of astronomy. This year the ASI meeting was held at Jaipur in March. RPL presented 2 posters: (i) Hands on Approach to Radio Astronomy, and (ii) Dual Mode Horn Antenna for Galactic 21 cm Hydrogen Line Observations. The second poster won the best poster award in the instrumentation category.

Public Outreach

The RPL gives special attention to public outreach, and is open to enthusiastic individuals for any help/advice they require regarding astronomy related activity. RPL members deliver informative lectures related to astronomy and instrumentation in astronomy in schools and colleges to make students aware of the career opportunities in astronomy. They are also informed of the latest developments.

We also have initiated the process of making videos for general public, which describe key radio astronomy concepts in lucid manner and documenting the working of big international facilities in India, like the GMRT (which is one the world's largest radio telescope). All these material will be freely available on our RPL website (http://www.iucaa.in/~rpl), and YouTube channel. RPL has also launched pages on the social media like Facebook, Twitter and YouTube for propagation of radio astronomy in India.

M.Sc. Practicals

M.Sc. students are expected to perform experiments as a part of curriculum. The students have to appear for practical exam to complete their course. Some of these experiments are conducted in RPL. Every year 3 to 4 experiments are performed by the students, and these have been a great success and will continue to be so. Some of the experiments are antenna radiation pattern measurement, detection of 21 cm Hydrogen line, Faraday rotation, and noise fundamentals.

Radio Astronomy Winter School

Radio Astronomy Winter School (RAWS) has been organized every year, jointly by IUCAA and NCRA. The school is largely meant for under-graduate students in science, pursuing B.Sc. (Physics/Electronics/Astronomy), and Engineering (B.E./ B.Tech.). Bright and highly motivated high school/junior college students, involved in amateur Astronomy, have been also encouraged to apply. Through lectures and hands-on Radio Astronomy experiments, the school exposes the participants to Astronomy in general, and Radio Astronomy in particular. The school has been immensely popular, and so far nine such schools have been organized since 2008. The experiments are conducted by RPL. The hands-on experiments included (i) Observations of Sun with the 4 m and 3 m telescope to determine the antenna power pattern, (ii) Observations of HI 21 cm line to neutral Hydrogen from the Galaxy, (iii) Measuring power patterns of various types of antennas using the antenna trainer kit, and (iv) Noise fundamentals. These experiments are designed to educate the students about techniques and instrumentation used in radio astronomy.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SCHOOL STUDENTS' SUMMER PROGRAMME

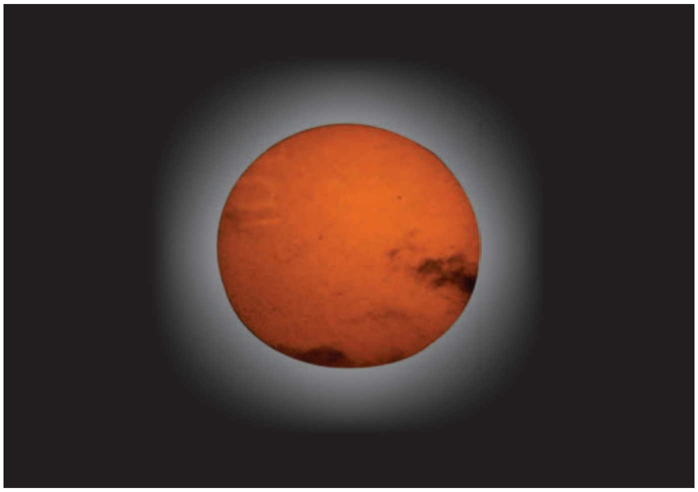
Ten students of classes 8 to 10 were selected to work on a project at IUCAA, and were guided by volunteering scientists, namely, Avyarthana Ghosh, Debajyoti Sarkar and Niladri Paul. This programme was conducted during April 4 - 15, 2016.
(For details see Khagol, No. 107, July 2016)

Zero Shadow Day was celebrated at IUCAA on May 13, 2016, with many students from IUCAA and across the city came to view the experiments done at MVS.
(For details see Khagol, No. 107, July 2016)

SUMMER ASTRONOMY CAMP

This camp was conducted during April 25 - May 20, 2016, and was coordinated by Samir Dhurde and Sonal Thorve, with experimental devices prepared by Maharudra Mate.
(For details see Khagol, No. 107, July 2016)

TRANSIT OF MERCURY - MAY 9, 2016



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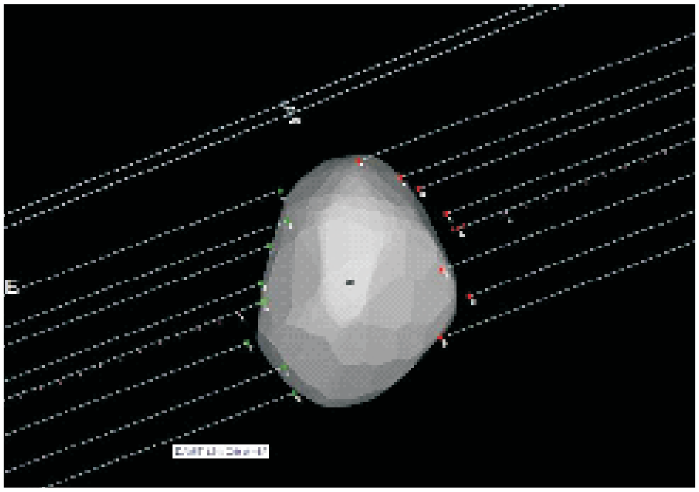


IUCAA Scipop played a major role in the nationwide campaign, initiated by the Astrononmical Society of India (ASI), to observe the Transit of Mercury. The event, thus, reached at least 100,000 people. This is a rare event and Samir Dhurde was the coordinator.
(For details see Khagol, No. 107, July 2016)

OUTREACH DURING ASI MEETING

IUCAA has helped to organise a Teacher Training workshop at Srinagar, Jammu and Kashmir, during the Astronomical Society of India (ASI) meeting held at the University of Kashmir (UoK), during May 5-7, 2016. A Transit of Mercury observation event was also coordinated by the ASI-POEC with assistance from Samir Dhurde, and UoK students and staff.
(For details see Khagol, No. 107, July 2016)

HALF-DAY STUDENT INTERACTIONS

Groups of students from Centre for Basic Sciences from Raipur, Aryabhat Foundation from Madhya Pradesh and Centre for Theoretical Physics, Jamia Milia Islamia from New Delhi visited MVS for interactions on March 10, April 6 and April 13, 2016 respectively. Sanjeev Dhurandhar (Emeritus Professor at IUCAA) interacted with the students. Samir Dhurde and Sonal Thorve conducted the sessions on Careers in Science and Astronomy.
(For details see Khagol, No. 107, July 2016)

GLOBAL ASTRONOMY MONTH

On the occasion of Global Astronomy Month, April 2016, IUCAA has organised public sky watching events on April 15 and 18, 2016. (For details see Khagol, No. 107, July 2016)

HANDS-ON MATHS AND SCIENCE WORKSHOP

As part of public outreach programmes of IUCAA, the Tata Trust, Mumbai, invited 36 primary and secondary school teachers for a Hands-on Maths and Science Workshop conducted at MVS, IUCAA, during August 8 - 10, 2016.
(For details see Khagol, No. 108, October 2016)

WORKSHOP ON BASIC ASTRONOMY AND TELESCOPE MAKING

To inculcate interest in astronomy among students of IISER, Tirupati and IIT, Tirupati, a two-day workshop was held at the Department of Physics, IISER, Tirupati, during September 11 - 12, 2016. The workshop was coordinated by Sudipta Dutta and Bhas Bapat (both from IISER, Tirupati) and Samir Dhurde.

(For details see Khagol, No. 108, October 2016)

WORKSHOP AT THE 3RD UNIVERSAL DESIGN SYMPOSIUM IN ASTRONOMY EDUCATION

Samir Dhurde was invited to present a workshop and attend a special symposium hosted at the National Astronomical Observatory of Japan, Tokyo, during September 24 - 26, 2016.

(For details see Khagol, No. 108, October 2016)

SECOND SATURDAY LECTURES

July	:	Jayant V. Narlikar on Cosmic Illusions.
August	:	Somak Raychaudhury on Our Place in Space.
September	:	Kaustubh Waghmare/Bhooshan Gadre on Measuring Lengths.
October	:	Samir Dhurde (IUCAA) on DIY Geology.
November	:	Shrikant Pawar (National Centre for Cell Science, Pune) on Wonders of Microbiology.
December	:	Dilip G. Kanhere (S. P. Pune University, Science Park) on The Ecology in and Around us.
January	:	Samir Dhurde, and Ashok Rupner (both from IUCAA) on Science with your Bicycle.
February	:	Shantipal Ohol (Government College of Engineering, Pune) on School level Robotics.

WHATSAPP OUTREACH UPDATES

IUCAA Scipop regularly sends updates about Space and Astronomy events on Whatsapp. If you are interested to receive these, please email your details to <scipop@gmail.com> with a subject "Whatsapp Updates" to register your phone number.

FAMELAB REGIONAL COMPETITION AND SCIENCE COMMUNICATION WORKSHOP

Ruchika Seth (IUCAA Research Scholar) and Sumeet Kulkarni (IUCAA Project Student) have participated in the Western Region leg of "FameLab", the world's biggest science communication competition, organised by the British Council, at the Indian Institute of Technology, Mumbai, during December 13 - 16, 2016. Samir Dhurde (IUCAA) was invited to present the Indian perspective on the field of science communication for science students.

(For details see Khagol, No. 109, January 2017)

WORKSHOP ON HANDS-ON ASTRONOMY

As part of IUCAA's teacher training efforts, a 2-day Workshop on Hands-on Astronomy was organised at MVS, IUCAA, during October 17 - 18, 2016, for the mentors of a voluntary organisation, ARCH, which has been working in the tribal belt in Gujarat. The workshop was coordinated by Samir Dhurde and Sonal Thorve, with support from Maharudra Mate and Nilesh Pokharkar.
(For details see Khagol, No. 109, January 2017)

OTHER REGULAR EVENTS

The Public Outreach groups have conducted 18 Science Toys workshops, 7 Basic Astronomy workshops, 6 campus visits, and 7 sky-watching programmes with an approximate reach to about 2,500 people. The mobile planetarium (Taramandal) was given out to volunteers from two different organisations trained by IUCAA, thus reaching to about 2,000 people.

NATIONAL SCIENCE DAY 2017

On February 28, 2017, it was revealed that IUCAA Science Day celebrations was just as popular, be it a Sunday or a weekday!
(For details see Khagol, No. 110, April 2017)

SPACE OLYMPIAD

As a part of the National Science Day celebrations, FISAT (Angamaly, Kerala) organised a Space Olympiad, during January 27 - 29, 2017. Sonal Thorve and Jyoti Hiremath were invited to represent IUCAA Scipop to conduct science toys demonstrations and sky-watching sessions.
(For details see Khagol, No. 110, April 2017)

EDUCATION AND SCIENCE COMMUNICATION

On January 24, 2017, Rohit Gupta (a free lancer) "Compasswallah", presented an informal slideshow/talk in MVS, IUCAA on his work as an independent historian of science and mathematics.

HANDS-ON ACTIVITIES IN MATHEMATICS AND SCIENCE

This Hands-on Activities was held at Muktangan Vidnyan Shodhika, IUCAA, during January 30 - February 4, 2017, with the support from the Tata Trusts, Mumbai.
(For details see Khagol, No. 110, April 2017)

ASTRO-FEST AND OUTREACH

Somak Raychaudhury presented IUCAA's role in Astronomy Education and Outreach, at the annual meeting of the Astronomical Society of India (ASI), held at Jaipur, during March 6 - 10, 2017. Samir Dhurde (IUCAA) helped to organise the Rajasthan Astronomy Festival on this occasion.
(For details see Khagol, No. 110, April 2017)

WORKSHOP ON BASIC ASTRONOMY AND TELESCOPE MAKING

To inculcate interest in Astronomy among the students of IISER, Kolkata, a workshop was organised during March 24 - 27, 2017, by the Centre of Excellence in Space Sciences - India, and the International Society for Optics and Photonics (SPIE), in association with the Public Outreach Programme of IUCAA. The coordinators were Dibyendu Nandi, Ayan Banerjee, and their enthusiastic students.

(For details see Khagol, No. 110, April 2017)

PUBLIC LECTURE

On February 14, 2017, Roberto Trotta (STFC Public Engagement Fellow, Imperial College, London), in association with the British Council, Pune, gave a public lecture on Why society needs astronomy and cosmology?

August 16, 2016

Title :
Recording the Music of the Universe

Speaker :
David McClelland
(The Australian National University, Canberra)

December 27, 2016

Title :
Symmetries and Spontaneous Symmetry-breaking in Coupled Dynamical Systems

Speaker :
Ramakrishna Ramaswamy
(Javaharlal Nehru University, New Delhi)

February 14, 2017

Title :
Why Society needs Astronomy and Cosmology

Speaker :
Roberto Trotta (Imperial College, London)

February 28, 2017

Title :
Topology Matters

Speaker :
Sunil Mukhi (IISER, Pune)

SHORT TERM COURSE ON DYNAMICAL SYSTEMS: THEORY AND APPLICATIONS

A short term course on Dynamical Systems: Theory and Applications, sponsored by IUCAA, was conducted at the Department of Applied Mathematics, Indian School of Mines, Dhanbad, during June 26 - 30, 2016. The coordinators were: Badam Singh Kushvah (ISM, Dhanbad), and Kanak Saha (IUCAA).
(For details see Khagol, No. 108, October 2016)

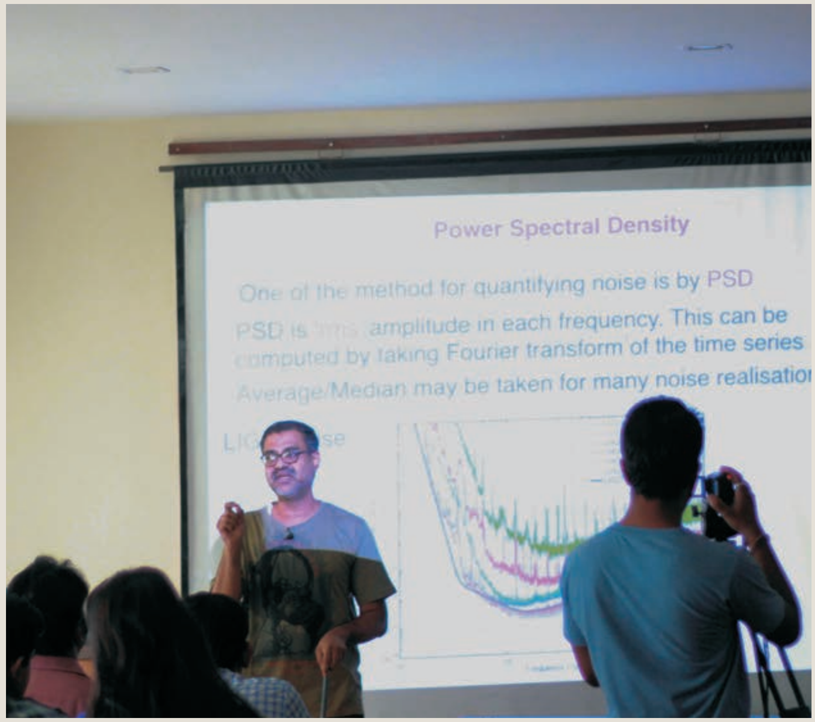
INTRODUCTORY SCHOOL ON ASTRONOMY

IUCAA sponsored Introductory School on Astronomy was held at Eliezer Joldan Memorial College, Leh, Ladakh, during September 13 - 14, 2016. This workshop was coordinated by Ranjan Gupta.
(For details see Khagol, No. 108, October 2016)

RESEARCH IN ASTRONOMY: OPPORTUNITIES AND CHALLENGES - III

A Conference on Research in Astronomy: Opportunities and Challenges - III was conducted at the Department of Physics, University of Calicut, Kozhikode, during July 18 - 19, 2016, under the auspices of the IUCAA Resource Centre (IRC) at the Cochin University of Science and Technology (CUSAT), Kochi. Ravikumar C.D., V.C. Kuriakose and Ranjeev Misra were the coordinators.
(For details see Khagol, No. 108, October 2016)

NATIONAL WORKSHOP ON GRAVITATIONAL WAVE ASTRONOMY



A National Workshop on Gravitational Wave Astronomy (NWGWA) was organized by the Department of Physics, Dibrugarh University, in collaboration with IUCAA, during November 2 - 4, 2016.
(For details see Khagol, No. 109, January 2017)

INTRODUCTORY WORKSHOP ON ASTROPHYSICS AND COSMOLOGY

The Introductory Workshop on Astrophysics and Cosmology, organized by the Department of Physics, Aliah University (AU), Kolkata, in collaboration with IUCAA Resource Centre (IRC), Kolkata, was held during September 26 - 28, 2016, at the Newtown Campus of AU. Mehedi Kalam (AU, and Visiting Associate of IUCAA), and Ranjeev Misra (IUCAA) were the conveners of the workshop.
(For details see Khagol, No. 109, January 2017)

WORKSHOP ON STRUCTURE FORMATION IN STANDARD COSMOLOGY

The Department of Mathematics, BITS-Pilani, Hyderabad Campus, organized a workshop on Structure Formation in Standard Cosmology, during December 19 - 23, 2016. Aseem Paranjape (IUCAA) as the coordinators, and Rahul Nigam, and Pradyumn K. Sahoo (both from BITS-Pilani, Hyderabad) as the conveners.
(For details see Khagol, No. 109, January 2017)

WORKSHOP ON INTRODUCTION TO SOLAR ASTROPHYSICS

The Workshop on Introduction to Solar Astrophysics was held during November 30 - December 2, 2016, at M.A. College, Kothamangalam, Kerala, under the auspices of the IUCAA Resource Centre, Kochi. Durgesh Tripathi was the coordinator, and Joe Jacob (Newman College, Thodupuzha) and Benoy M. D. (M. A. College) were the local conveners of the workshop.
(For details see Khagol, No. 109, January 2017)

IUCAA- APT WORKSHOP ON VIRTUAL OBSERVATORY

IUCAA Resource Centre at Cochin University of Science and Technology (CUSAT), Kochi, along with the Academy of Physics Teachers (APT), Kerala, organised a Workshop on Virtual Observatory during July 16 – 17, 2016 at S. H. College, Chalakudy, Kerala. Nijo Varghese (S. H. College), G. Harikrishnan (Government College, Madappally, and Secretary, APT) and Joe Jacob (Newman College, Thodupuzha) were the local organizers/coordinators of the workshop.

(For details see Khagol, No. 109, January 2017)

WORKSHOP ON STATISTICAL ANALYSIS IN COSMOLOGY

The Workshop on Statistical Analysis in Cosmology was conducted at the Department of Physics, Cochin University of Science and Technology, Kochi, during January 12 - 14, 2017. Tarun Souradeep and Titus K. Mathew (Department of Physics, CUSAT) were the coordinators of the workshop.
(For details see Khagol, No. 110, April 2017)

WORKSHOP ON STELLAR ASTROPHYSICS

The Workshop on Stellar Astrophysics was conducted at the Department of Physics, Christ University, Bengaluru, during February 2 - 4, 2017, sponsored by IUCAA. Paul K. T. (Christ University) and Ranjan Gupta were the coordinators.
(For details see Khagol, No. 110, April 2017)

Farooq Ahmad

Gravitational clustering of galaxies: Derivation of two-point galaxy correlation function using statistical mechanics of cosmological many-body problem

We derive the spatial pair correlation function in gravitational clustering for extended structure of galaxies (e.g., galaxies with haloes) by using statistical mechanics of cosmological many-body problem. Our results indicate that in the limit of point masses ($\epsilon = 0$), the two-point correlation function varies as inverse square of relative separation of two galaxies. The effect of softening parameter 'ϵ' on the pair correlation function is also studied and results indicate that two-point correlation function is affected by the softening parameter when the distance between galaxies is small. However, for larger distance between galaxies, the two-point correlation function is not affected at all. The correlation length r_0 derived by our method depends on the random dispersion velocities $\langle V^2 \rangle^{1/2}$ and mean number density $\bar{n}$, which is in agreement with N-body simulations and observations. Further, our results are applicable to the clusters of galaxies for their correlation functions and we apply our results to obtain the correlation length r_0 for such systems, which again agrees with the data of N-body simulations and observations. This research has been done in collaboration with Manzoor A. Malik and M. Maqbool Bhat.

Sk. Saiyad Ali

The visibility based Tapered Gridded Estimator (TGE) for the redshifted 21-cm power spectrum

We present the improved visibility based Tapered Gridded Estimator (TGE) for the power spectrum of the diffuse sky signal. The visibilities are gridded to reduce the computation and tapered through a convolution to suppress the contribution from the outer regions of the telescope's field of view. The TGE also internally estimates the noise bias and accurately subtracts this out to give an unbiased estimate of the power spectrum. An earlier version of the 2D TGE for the angular power spectrum C_ℓ is improved and then extended to obtain the 3D TGE for the power spectrum $P(k)$ of the 21-cm brightness temperature fluctuations. We present analytic formulas for predicting the variance of the binned power spectrum. The estimator and its variance predictions are validated using simulations of 150 MHz GMRT observations. We find that the estimator accurately recovers the input model for the 1D Spherical Power Spectrum $P(k)$ and the 2D Cylindrical Power Spectrum $P(k_\perp, k_\parallel)$, and the predicted variance is also in reasonably good agreement with the simulations. This research work has been done in collaboration with S. Chaudhuri, S. Bharadwaj, S. Chatterjee, N. Roy and A. Ghosh.

The prospects of measuring the angular power spectrum of the diffuse Galactic synchrotron emission with SKA1 Low

The diffuse Galactic synchrotron emission (DGSE) is the most significant diffuse foreground component for future cosmological 21-cm observations. The DGSE is also an important probe of the cosmic ray electron and magnetic field distributions in the turbulent interstellar medium (ISM) of our Galaxy. In this work, we briefly review the Tapered Gridded Estimator (TGE), which can be used to quantify the angular power spectrum C_ℓ of the sky signal directly from the visibilities measured in radio interferometric observations. The salient features of the TGE are: (i) it deals with the gridded data, which makes it computationally very fast, (ii) it avoids a positive noise bias, which arises from the system noise inherent to the visibility data, and (iii) it allows us to taper the sky response and thereby suppresses the contribution from unsubtracted point sources in the outer parts and the sidelobes of the antenna beam pattern. We also summarize earlier work, where the TGE was used to measure the C_ℓ of the DGSE using 150 MHz GMRT data. Earlier measurements of C_ℓ are restricted to $\ell \leq \ell_{max} \sim 10^3$ for the DGSE, the signal at the larger ℓ values is dominated by the residual point sources after source subtraction. The higher sensitivity of the upcoming SKA1 Low will allow the point sources to be subtracted to a fainter level than possible with existing telescopes. We predict that it will be possible to measure the C_ℓ of the DGSE to larger values of ℓ_{max} with SKA1 Low. Our results show that it should be possible to achieve $\ell_{max} \sim 10^4$ and $\sim 10^5$ with 2 minutes and 10 hours of observation respectively. This project has been done in collaboration with S. Bharadwaj, S. Choudhuri, A. Ghosh and N, Roy.

G. Ambika

Emergent dynamics in interacting systems with differing time scales

We study the emergent states of two interacting non-linear systems with differing dynamical time scales. We find that the inability of the interacting systems to fall in step leads to a frequency-synchronized state or as the mismatch in time scale increases, to a state of no oscillations or amplitude death. This has relevance in several contexts like coupled ocean-atmosphere system used in climate studies for the interaction between a fast oscillating atmosphere and slowly changing ocean, where we could show occurrence of multi-stable periodic states and steady states of convection coexisting in the system, with a complex basin structure. This work has been done in collaboration with Kajari Gupta.

Heterogeneity measure for recurrence networks from time series

Recurrence networks are important statistical tools used for the analysis of time series data with several practical applications. Recently, we developed a general method for the construction and analysis of unweighted recurrence networks from time series. This provides a uniform framework for the non-subjective comparison of the statistical measures of the recurrence networks constructed from various chaotic attractors. We use recurrence network measures to study how the presence of white and coloured noise in the chaotic time series affects the structure of the underlying attractor. These measures are shown to be effective in identifying the nature of noise contamination in a real world data. In this context, we reported a new heterogeneity measure that can be used to compare the degree heterogeneity of recurrence networks constructed from the time series of several low dimensional chaotic attractors and this provides a single index to compare the structural complexity of chaotic attractors. This work has been done in collaboration with Rinku Jacob, K.P. Harikrishnan and Ranjeev Misra.

Subenoy Chakraborty

A new interacting two fluid model and its consequences

In the background of a homogeneous and isotropic spacetime with zero spatial curvature, we consider interacting scenarios between two barotropic fluids; one is the pressureless dark matter (DM) and the other one is dark energy (DE), in which the equation of state (EoS) in DE is either constant or time dependent. In particular, for constant EoS in DE, we show that the evolution equations for both fluids can be analytically solved. For all these scenarios, the model parameters have been constrained using the current astronomical observations from Type Ia Supernovae, Hubble parameter measurements, and baryon acoustic oscillations distance measurements. Our analysis shows that for both, constant and variable EoS in DE, a very small but non-zero interaction in the dark sector is favoured while the EoS in DE can predict a slight phantom nature, i.e., the EoS in DE can cross the phantom divide line '-1'. On the other hand, although the models with variable EoS describe the observations better, but the Akaike Information Criterion supports models with minimal number of parameters. However, it is found that all the models are very close to the ΛCDM. This work has been done in collaboration with G.S. Sharov, S. Bhattacharya, S. Pan and Rafael C. Nunes.

Quintom cosmological model and some possible solutions using Lie and Noether symmetries

The present work deals with a quintom model of dark energy in the framework of a spatially flat isotropic and homogeneous Friedmann–Lemaitre–Robertson–Walker (FLRW) universe. At first, Lie point symmetry is imposed to the system and the unknown coupled potential of the model is determined. Then Noether symmetry, which is also a point like symmetry of the Lagrangian, is imposed on the physical system and the potential takes a general form. It is shown that the Lie algebra of Noether symmetry is a sub-algebra of the corresponding Lie algebra of the Lie symmetry. Finally, a point transformation in the three dimensional augmented space is performed suitably so that one of the variables become cyclic and as a result there is considerable simplification to the physical system. Hence conserved quantities (i.e., constants of motion) are expressed in a compact form and cosmological solutions are evaluated and analyzed in the present context. This work has been done in collaboration with Sourav Dutta and Muthusamy Lakshmanan.

Ramesh Chandra

Blowout jets and impulsive eruptive flare in a bald-patch topology

We analyze observations of a series of recurrent broad jets observed in AR 10484 on 21-24 October 2003. In particular, one of them occurred simultaneously with an M2.4 flare on 23 October at 02:41 UT (SOLA2003-10-23). Both events were observed by the ARIES Hα Solar Tower-Telescope, TRACE, SOHO, and RHESSI instruments. The flare was very impulsive and followed by a narrow CME. A local force-free model of AR 10484 is the basis to compute its topology. We find bald patches (BPs) at the flare site. This BP topology is present for at least two days before to events. Large scale field lines, associated with the BPs, represent open loops. This is confirmed by a global potential free source surface (PFSS) model. Following the brightest leading edge of the Hα and EUV jet emission, we can temporarily associate these emissions with a narrow CME. Considering their characteristics, the observed broad jets appear to be of the blowout class. As the most plausible scenario, we propose that magnetic reconnection could occur at the BP separatrices forced by the destabilization of a continuously reformed flux rope underlying them. The reconnection process could bring the cool flux-rope material into the reconnected open field lines driving the series of recurrent blowout jets and accompanying CMEs. Based on a model of the coronal field, we compute the AR 10484 topology at the location where flaring and blowout jets occurred from 21 to 24 October 2003. This topology can consistently explain the origin of these events. This work has been done in collaboration with C.H. Mandrini, B. Schmieder, et al.

Peculiar stationary EUV wave fronts in the eruption on 2011 May 11

We present and interpret the observations of extreme ultraviolet (EUV) waves associated with a filament eruption on 2011 May 11. The filament eruption also produces a small B-class two ribbon flare and a coronal mass ejection. The event is observed by the Solar Dynamic Observatory with high spatio-temporal resolution data recorded by the Atmospheric Imaging Assembly. As the filament erupts, we observe two types of EUV waves (slow and fast) propagating outwards. The faster EUV wave has a propagation velocity of $\sim$ 500 km s^{-1} and the slower EUV wave has an initial velocity of $\sim$ 120 km s^{-1}. We report, for the first time, that not only does the slower EUV wave stop at a magnetic separatrix to form bright stationary fronts, but also the faster EUV wave transits a magnetic separatrix, leaving another stationary EUV front behind. This work has been done in collaboration with P.F. Chen, A. Fulara, A.K. Shrivastava and W. Uddin.

Suresh Chandra

Anomalous absorption in glycolaldehyde in a cosmic object

The glycolaldehyde is detected towards the Galactic centre source Sgr B2(N) and towards the massive star-forming region G31.41+0.31 through b-type transitions. The levels for b-type transitions can be classified into two groups: (i) with $k_a + k_c$ = odd (set I), and (ii) with $k_a + k_c$ = even (set II). For each of the sets I and II, we have calculated energies of 100 rotational levels. These levels are connected through radiative and collisional transitions. The Einstein A-coefficients for the radiative transitions among the levels are calculated. The collisional rate coefficients are calculated with the help of a scaling law. Using the radiative and collisional transitions probabilities, for each of the sets I and II, we have solved a set of statistical equilibrium equations coupled with the equations of radiative transfer. Two transitions $1_{10}-1_{01}$ and $3_{12}-3_{03}$ at 13.477 GHz and 17.981 GHz, respectively of set I, and one transition $2_{11}-2_{02}$ at 15.176 GHz of set II are found to have anomalous absorption. These transitions may play important role in the identification of glycolaldehyde in a cosmic object. This work has been done in collaboration with Mohit K. Sharma, Monika Sharma and A.K. Sharma.

Very low probability of detection of TiH_2 molecule in a cosmic object

In the year 1979, identification of TiH and TiO in the atmosphere of cool M-type stars has been historical, as the Titanium was discovered for the first time in a cosmic object. Third Titanium-bearing molecule, TiO_2, also is identified in the red supergiant VY CMa. Thus, there is a natural question about the detection of TiH_2 molecule, as the cosmic abundance of hydrogen is approximately 2000 times larger than that of the oxygen. The large abundance of H as compared to O may not suffice, as for example, the probability of formation of CO is much larger than that of CH. Without going into the details of Chemistry, we have discussed that the probability of detection of TiH_2 in a cosmic object is very low, though it has a large electric dipole moment. This work has been done in collaboration with Mohit K. Sharma and Monika Sharma.

Asis Chattopadhyay

Incomplete data in astrostatistics

During the past two decades, the interdisciplinary field of astrostatistics has newly emerged in order to study important astrophysical issues through appropriate statistical analysis. Statistical analysis with missing data is an important problem, as the problem of incomplete information is very common in many situations. Missing values occur for a variety of reasons, from recording problems to instrument limitations. In particular, when data are combined from multiple archives or instruments, it is virtually certain that some objects will not be present in all of the contributing sources. Standard techniques of missing data analysis may not be equally applicable for astronomical data analysis as the concept of ?missing at random? is not likely to be true for such type of data. In the present study, a review of the papers related to missing information in astronomical data and techniques for analysis of missing data have been considered. A new method developed by Tuli De, et al. (2016) has also been discussed.

Classification under non-Gaussian set-up: An astrostatistical problem

Proper classification of different astronomical objects is of great importance in order to study the nature of origin of those objects. Although, clustering and classification techniques are exploratory in nature, there are model based techniques which use distributional assumptions extensively. Many astro nomical data sets related to galaxies, globular clusters, pulsars, among others, show complicated non-Gaussian nature. For classification, a common practice is to use a discriminant function based on normality assumption, which may result in severe amount of loss of accuracy if the underlying distribution is quite different from Gaussian. The present work makes an attempt to develop a likelihood ratio based procedure for classification when the underlying data are skewed and in addition, there are some missing observations. The efficiency of the classifier has been verified on the basis of simulation and also a real data set corresponding to different parameters of Globular Clusters (GCs) of an elliptical galaxy NGC 5128. This work has been done in collaboration with Tuli De and Rahul Bhattacharya.

Surajit Chattopadhyay

Reconstruction of $f(T)$ gravity with interacting variable generalized Chaplygin gas and the thermodynamics with corrected entropies

The present work reports a study on variable generalized Chaplygin gas (VGCG) interacting with pressure less dark matter (DM) with interaction term Q chosen in the form $Q = 3H\delta\rho_\Lambda$, where ρ_Λ denotes the density of the VGCG. Detailed cosmology of the interacting VGCG has been studied and a quintom behaviour of the equation of state (EoS) parameter has been observed. A statefinder analysis has shown attainment of ΛCDM fixed point by the interacting VGCG. Subsequently, a reconstruction scheme for $f(T)$ gravity has been presented based on the interacting VGCG with power-law form of scale factor. The EoS parameter corresponding to the reconstructed $f(T)$ has shown quintom behaviour. Finally, we have studied the GSL for this reconstructed $f(T)$ gravity using 'modified first law of thermodynamics'. Next we have used the power-law and logarithmic corrected forms of entropy for the future event horizon. In $f(T)$ gravity, the entropy area relation has been modified to $A \rightarrow A(1 + f_T)$, because it has been already observed that $f_{TT} << 1$ and it is consistent with the existing literature. Although the GSL has been found to be always valid in the case of usual Bekenstein-Hawking area law, it fails to hold in power-law entropy correction. The time derivative of total entropy under power-law and logarithmic corrections have been plotted and it has been observed that $\dot{S}_{total}$ corresponding to the power-law entropy correction has stayed at negative level, which shows that the GSL does not hold for the reconstructed $f(T)$ gravity under power-law entropy correction. However, for logarithmic corrections the GSL has been found to hold irrespective of γ. This result deviates from Bamba, et al., Astrophys. Space Sci. **344**, 259 (2013) in the sense that in the said reference, the GSL had a conditional validity for both of the corrections in the case of future event horizon. However, in the present case, the GSL has failed to hold in power-law correction and has unconditional validity in logarithm correction with future event horizon as the enveloping surface of the universe.

Modified Chaplygin gas equation of state on viscous dissipative extended holographic Ricci dark energy and the cosmological consequences

The present project reports a study on modified Chaplygin gas (MCG) based reconstruction scheme for extended holographic Ricci dark energy (EHRDE) in the presence of viscous type dissipative term. The dissipative effect has been described by using Eckart approach. Under the assumption that the universe is filled with MCG-EHRDE with the influence of bulk viscosity, we have studied the cosmological dynamics, where the bulk viscosity coefficient has been chosen in a particular time varying form: $\xi = \xi_0 + \xi_1 H + \xi_2(\dot{H} + H^2)$, where ξ_0, ξ_1 and ξ_2 are constant coefficients and H is the Hubble parameter. Furthermore, we have reconstructed the potential and dynamics of viscous MCG-EHRDE as scalar field. We have reconstructed H and then considering $\rho_R = \rho_c$ reconstructed EoS parameter for EHRDE w_R involving parameters of NHRDE and MCG as well. This reconstructed w_R when multiplied by ρ_R with reconstructed H produced thermodynamic pressure p_R of MCG-EHRDE which is added to the bulk viscous pressure Π to get the effective pressure p_{eff}. Considering bulk viscous pressure $\Pi = -3H\xi$, and taking the viscosity coefficient as a time varying one in the form: $\xi = \xi_0 + \xi_1 H + \xi_2(\dot{H} + H^2)$, we have derived the expression of effective pressure $p_{eff} = p_R + \Pi$, and subsequently the effective EoS parameter $w_{eff} = \frac{p_{eff}}{\rho_R}$ from modified conservation equation as functions of scale factor: $a = (1+z)^{-1}$, where z is the redshift. Plotting against redshift, we observed that $\xi > 0$ is satisfied, and ξ is increasing with evolution of the universe. We also observed that absolute value of bulk viscous pressure is monotonically increasing function of scale factor or in other words decreasing with z. This indicates the increasing effect of bulk viscous pressure with evolution of the universe. From this we may interpret that the internal friction caused by different cooling rates is increasing with expansion of the universe, and thereby, the rate of conversion of kinetic energy of the particles into heat is increasing. On the other hand, the thermodynamic pressure due to MCG-EHRDE is decaying. However, negative effective pressure comes out to be a monotonically increasing function of z. This means that absolute effective pressure is increasing with evolution of the universe due to the increasing influence of bulk viscous pressure. Next comes the effective EoS parameter w_{eff}, which is found to transit from quintessence ($w_{eff} > -1$) to phantom ($w_{eff} < -1$) era at $0 \lesssim z \lesssim 0.40$. Hence the w_{eff} seems to behave like quintom. Thereafter, we have studied the statefinder trajectories to discern its departure from ΛCDM, and finally investigated the validity of the generalized second law of thermodynamics (GSL) considering event horizon as the enveloping horizon of the universe.

Tanuka Chattopadhyay

Clustering of gamma-ray bursts through kernel principal component analysis

We have considered the problem related to clustering of gamma-ray bursts (from 'BATSE' catalogue) through kernel principal component analysis, in which our proposed kernel outperforms results of other competent kernels in terms of clustering accuracy, and we obtain three physically interpretable groups of gamma-ray bursts. The effect of the suggested kernel, in combination with kernel principal component analysis in revealing natural clusters in noisy and nonlinear data while reducing the dimension of the data is also explored in two simulated data sets. This work has been done in collaboration with Soumita Modak and Asis Kumar Chattopadhyay.

Bhag Chand Chauhan

Quark-lepton complementarity model based predictions for θ_{13}^{pmns} with neutrino mass hierarchy

In the light of recent experimental results on θ_{13}^{pmns}, we re-investigate the complementarity between the quark and lepton mixing matrices and obtain predictions for most unsettled neutrino mixing parameters like θ_{23}^{pmns} and CP violating phase invariants

J, S_1 and S_2. This work is motivated by our previous work where in a QLC model, we predicted the value for $\theta_{13}^{pmns} = (9^{+1}_{-2})^{\circ}$, which was found to be in strong agreement with the experimental results. In the QLC model, the non-trivial correlation between CKM and PMNS mixing matrices is given by a correlation matrix (V_c). We do numerical simulation and estimate the texture of the V_c, and we get a small deviation from the Tri-Bi-Maximal (TBM) texture and a large from the Bi-Maximal one, which is consistent with the work already reported in literature. Further, we obtain quite constrained limits for $sin^2\theta_{23}^{pmns} = 0.4235^{+0.0032}_{-0.0043}$, that is narrower to the existing ones. We also obtain the constrained limits for the three CP violating phase invariants J, S_1 and S_2 as: $J < 0.0315$, $S_1 < 0.12$ and $S_2 < 0.08$, respectively. This research has been done in collaboration with Gazal Sharma.

Dark matter and neutrinos

The Keplerian distribution of velocities is not observed in the rotation of large scale structures, as found in the rotation of spiral galaxies. The deviation from Keplerian distribution provides compelling evidence of the presence of non-luminous matter, i.e., dark matter. There are several astrophysical motivations for investigating the dark matter in and around the galaxy as halo. In this work, we address various theoretical and experimental indications pointing towards the existence of this unknown form of matter. Amongst its constituents, neutrino is one of the most prospective candidates. We know the neutrinos oscillate and have tiny masses, but there are also signatures for existence of heavy and light sterile neutrinos and possibility of their mixing. Altogether, the role of neutrinos is of great interests in cosmology and understanding dark matter. This project has been done in collaboration with Gazal Sharma.

Himadri Sekhar Das

Magnetic field geometry of the large globule CB 34

The results of optical polarimetric observations of a Bok globule CB34 to study the magnetic field structure on large scales (10^5 - 10^6 AU), which is combined with archival sub-mm observations to characterize the magnetic field structure of CB34 on small scales (10^4 - 10^5AU) have been reported. The optical polarization measurements indicate that the magnetic field in the globule is constrained to a maximum radius of 10^5AU around the core, out to densities not smaller than 10^4cm^{-3}. Our study is mainly concentrated on two sub-millimetre cores C1 and C2 of CB34. The direction of magnetic field of core C2 is found to be nearly perpendicular to the CO outflow direction of the globule. The magnetic field of core C1 is almost aligned with the minor axis of the core, which is typical for magnetically dominated star formation models. The mean value of offset between the minor axis of core C2 and the outflow direction is found to be 14°, which suggests that the direction of the outflow is almost aligned with the minor axis of core C2. The magnetic field strength in the plane-of-sky for cores C1 and C2 is estimated to be $\approx 34\mu$G and $\approx 70\mu$G. This work has been done in collaboration with A. Das, Biman J. Medhi and S. Wolf.

Study of magnetic field geometry and extinction in Bok globule CB130

The peripheral magnetic field structure of Bok globule CB130 has been traced, by estimating the linear polarization of its field stars in the R band. The magnetic field orientation sampled by these stars, aligned on average among themselves and the polarization produced within the cloud has a different direction from that of Galactic plane with an offset of 53°. The offset between minor axis and the mean magnetic field of CB130 is found to be 80°. The estimated strength of the magnetic field in the plane-of-the-sky is $\sim$116$\pm$19 μG. We have constructed the visual extinction map using Near Infrared Color Excess (NICE) method to see the dust distribution around CB130. Contours of Herschel SPIRE 500μm dust continuum emission maps of this cloud is over-plotted on the visual extinction map, which shows the regions having higher optical extinction corresponds to higher densities of dust. Three distinct high dust density cores (named as C1, C2, and C3) are identified in the extinction map. It is observed that the cores C1 and C3 are located close to the previously known cores CB130-1 and CB130-2 respectively. Estimate of visual extinction of some moderately obscured stars of CB130 are made utilizing near-infra red photometry. It is observed that there is a feeble dependence of polarization on extinction; and polarization efficiency (defined as p/AV) of the dust grains decreases with the increase in extinction. This work has been done in collaboration with A. Chakraborty.

Sudipta Das

Study of parametrized dark energy models with a general non-canonical scalar field

In this work, we have considered various dark energy models in the framework of a non-canonical scalar field with a Lagrangian density of the form: $\mathcal{L}(\phi, X) = f(\phi)X\left(\frac{X}{M_{Pl}^4}\right)^{(\alpha-1)} - V(\phi)$, which provides the standard canonical scalar field model for $\alpha = 1$ and $f(\phi) = 1$. In this particular non-canonical scalar field model, we have carried out the analysis for $\alpha = 2$. We have then obtained cosmological solutions for constant as well as variable equation of state parameter ($\omega_\phi(z)$) for dark energy. We have also performed the data analysis for three different functional forms of $\omega_\phi(z)$ by using the combination of SN Ia, BAO and CMB datasets. We have found that for all the choices of $\omega_\phi(z)$, the SN Ia + CMB/BAO dataset favours the past decelerated and recent accelerated expansion phase of the universe. Furthermore, using the combined dataset, we have observed that the reconstructed results of $\omega_\phi(z)$ and $q(z)$ are almost choice independent and the resulting cosmological scenarios are in good agreement with the ΛCDM model (within the 1σ confidence contour). We have also derived the form of the potentials for each model and the resulting potentials are found to be a quartic potential for constant ω_ϕ and a polynomial in ϕ for variable ω_ϕ. This work has been done in collaboration with Abdulla Al Mamon.

Constraints on reconstructed dark energy model from SN Ia and BAO/CMB observations

The motivation of the present work is to reconstruct a dark energy model through the dimensionless dark energy function $\chi(z)$, which is the dark energy density in units of its present value. In this work, we have shown that a scalar field ϕ having a phenomenologically chosen $\chi(z)$ can give rise to a transition from a decelerated to an accelerated phase of expansion for the universe. We have examined the possibility of constraining various cosmological parameters (such as the deceleration parameter and the effective equation of state parameter) by comparing our theoretical model with the latest Type Ia Supernova (SN Ia), Baryon Acoustic Oscillations (BAO) and Cosmic Microwave Background (CMB) radiation observations. Using the joint analysis of the SN Ia+BAO/CMB dataset, we have also reconstructed the scalar potential from the parametrized $\chi(z)$. The relevant potential is found, which comes out to be a polynomial in ϕ . From our analysis, it has been found that the present model favours the standard ΛCDM model within 1σ confidence level. This work has been done in collaboration with Abdulla Al Mamon and Kazuharu Bamba.

Ujjal Debnath

Entropy bound of horizons for accelerating, rotating and charged Plebanski-Demianski black hole

We first review the accelerating, rotating and charged Plebanski-Demianski (PD) black hole, which includes the Kerr-Newman rotating black hole and the Taub-NUT spacetime. The main feature of this black hole is that it has 4 horizons like event horizon, Cauchy horizon and two accelerating horizons. In the non-extremal case, the surface area, entropy, surface gravity, temperature, angular velocity, Komar energy and irreducible mass on the event horizon and Cauchy horizon are presented for PD black hole. The entropy product, temperature product, Komar energy product and irreducible mass product have been found for event horizon and Cauchy horizon. All these relations are dependent on the mass of the PD black hole and other parameters. So all the products are not universal for PD black hole. The entropy and area bounds for two horizons have been investigated. Also, we found the Christodoulou-Ruffini mass for extremal PD black hole. Finally, using first law of thermodynamics, we also found the Smarr relation for PD black hole.

Reconstructions of $f(T)$ gravity from entropy corrected holographic and new agegraphic dark energy models in power-law and logarithmic versions

Here, we peruse cosmological usage of the most promising candidates of dark energy in the framework of $f(T)$ gravity theory, where T represents the torsion scalar teleparallel gravity. We reconstruct the different $f(T)$ modified gravity models in the spatially flat Friedmann-Robertson-Walker (FRW) universe according to entropy-corrected versions of the holographic and new agegraphic dark energy models in power-law and logarithmic corrections, which describe accelerated expansion history of the universe. We conclude that the equation of state parameter of the entropy-corrected models can transit from quintessence state to phantom regime as indicated by recent observations or can lie entirely in the phantom region. Also, using these models, we investigate the different erase of the stability with the help of the squared speed of sound. This work has been done in collaboration with Pameli Saha.

S. Dev

Deviations in tribimaximal mixing from sterile neutrino sector

We explore the possibility of generating a non-zero $Ue3$ element of the neutrino mixing matrix from tribimaximal neutrino mixing by adding a light sterile neutrino to the active neutrinos. Small active-sterile mixing can provide the necessary deviation from tribimaximal mixing to generate a non-zero θ_{13} and atmospheric mixing θ_{23} different from maximal. Assuming no CP-violation, we study the phenomenological impact of sterile neutrinos in the context of current neutrino oscillation data. The tribimaximal pattern is broken in such a manner that the second column of tribimaximal mixing remains intact in the neutrino mixing matrix. This research work has been done in collaboration with Desh Raj and Radha Raman Gautam.

Non-zero U_{e3} in the presence of eV scale sterile neutrino

Motivated by hints from short baseline anomalies, we study the phenomenological impact of eV scale sterile neutrinos in the light of current neutrino oscillation data, assuming CP conservation. Small active-sterile mixing induces deviations from exact tribimaximal mixing by generating a non-zero θ_{13} and atmospheric mixing θ_{23} different from maximal. A non-zero U_{e3} element of the neutrino mixing matrix is generated by adding a light sterile neutrino to the known active neutrinos. Active-sterile mixing angles obtained in this analysis are small enough to lie well within their known experimental ranges. This research work has been done in collaboration with Radha Raman Gautam and Desh Raj.

Broja Gopal Dutta

Temporal variability from the two-component advective flow solution and its observational evidence

In the propagating oscillatory shock model, the oscillation of the post-shock region, i.e., the Compton cloud, causes the observed low-frequency quasi-periodic oscillations (QPOs). The evolution of QPO frequency is explained by the systematic variation of the Compton cloud size, i.e., the steady radial movement of the shock front, which is triggered by the cooling of the post-shock region. Thus, analysis of energy-dependent temporal properties in different variability time scales can diagnose the dynamics and geometry of accretion flows around black holes. We study these properties for the high inclination black hole source XTE J1550-564 during its 1998 outburst and the low-inclination black hole source GX 339-4 during its 2006-07 outburst using RXTE/PCA data, and we find that they can satisfactorily explain the time lags associated with the QPOs from these systems. We find a smooth decrease of the time lag as a function of time in the rising phase of both sources. In the declining phase, the time lag increases with time. We find a systematic evolution of QPO frequency and hard lags in these outbursts. In XTE J1550-564, the lag changes from hard to soft (i.e., from a positive to a negative value) at a crossing frequency (ν_C) of $\sim$ 3.4 Hz. We present possible mechanisms to explain the lag behaviour of high and low-inclination sources within the framework of a single two-component advective flow model (TCAF).This work has been done in collaboration with Sandip K. Chakrabarti.

Inclination dependent time lag properties in black hole binaries

We study the energy dependent temporal properties in different variability time scale for the edge on (GRS 1915+105 and XTE J1550-564) and face on (GX 339-4 and XTE J1650-500) black hole sources during outbursts. We find a smooth decrease of time-lag as a function of time in the rising phase of both the sources. In the declining phase, the time-lag increases with time. We find a systematic evolution of QPO frequency and also evolution of the hard lags in black hole binaries. In high inclination source, however, lag changes from hard to soft (i.e., from a positive to a negative value) at a crossing frequency. We discussed all possible mechanisms which could be controlling the time lag. Specifically, we showed that if we add up the qualitative variations of lags, then the high inclination objects could have negative time lags due to reflection and focusing effects. We incorporate all possible mechanisms and appropriate geometry and found very satisfactory explanations of these lag property with two component advective flow model.

Jibitesh Dutta

Scalar-fluid interacting dark energy: Cosmological dynamics beyond the exponential potential

We extend the dynamical systems analysis of scalar-fluid interacting dark energy models performed in C. G. Boehmer, et al. Phys. Rev. D **91**, 123002 (2015) by considering scalar field potentials beyond the exponential type. The properties and stability of critical points are examined using a combination of linear analysis, computational methods and advanced mathematical techniques, such as centre manifold theory. We show that the interesting results obtained with an exponential potential can generally be recovered also for more complicated scalar field potentials. In particular, employing power law and hyperbolic potentials as examples, we find late time accelerated attractors, transitions from dark matter to dark energy domination with specific distinguishing features, and accelerated scaling solutions capable of solving the cosmic coincidence problem. This work has been done in collaboration with Wompherdeiki Khyllep and Nicola Tamanini.

Modified Bekenstein-Hawking system in $f(R)$ gravity

The present work deals with four alternative formulation of Bekenstein system on event horizon in $f(R)$ gravity. While thermodynamical laws holds in universe bounded by apparent horizon, these laws break down on event horizon. With alternative formulation of thermodynamical parameters (temperature and entropy), thermodynamical laws hold on event horizon in Einstein gravity. With this motivation, we extend the idea of generalised Hawking temperature and modified Bekenstein entropy in homogeneous and isotropic model of universe on event horizon and examine whether thermodynamical laws hold in f(R) gravity. Specifically, we examine and compare validity of generalised second law of thermodynamics (GSLT) and thermodynamical equilibrium (TE) in four alternative modified Bekenstein scenarios. As dark energy is a possible dominant candidate for matter in the univerese and holographic dark energy (HDE) can give effective description of f(R) gravity, so matter in the universe is taken as in the form interacting HDE. In order to understand the complicated expressions, finally the above laws are examined from graphical representation using three Planck data sets and it is found that generalised/modified Hawking temperature has a crucial role in making perfect thermodynamical system. This work has been done in collaboration with Saugata Mitra and Binod Chetry.

Sunandan Gangopadhyay

Constraints on rainbow gravity functions from black hole thermodynamics

We investigate the thermodynamic properties of black holes in the framework of rainbow gravity. By considering rainbow functions in the Schwarzschild metric, and Reissner-Nordström black holes, remnant and critical masses are found to exist. Demanding the universality of logarithmic corrections to the semi-classical area law for the entropy leads to constraining the form of the rainbow functions. The mass output and the radiation rate for these constrained form of rainbow functions have been computed for different values of the rainbow parameter and have striking similarity to those derived from the generalized uncertainty principle. This work has been done in collaboration with Abhijit Dutta.

Non-commutative effects of spacetime on holographic superconductors

The Sturm-Liouville eigenvalue method is employed to analytically investigate the properties of holographic superconductors in higher dimensions in the framework of Born-Infeld electrodynamics incorporating the effects of non-commutative spacetime. In the background of pure Einstein gravity in non-commutative spacetime, we obtain the relation between the critical temperature and the charge density. We also obtain the value of the condensation operator and the critical exponent. Our findings suggest that higher the value of non-commutative parameter and Born-Infeld parameter make the condensate harder to form. We also observe that the critical temperature depends on the mass of the black hole and higher value of black hole mass is favourable for the formation of the condensate.This work has been done in collaboration with Debabrata Ghorai.

Sushant G. Ghosh

Rotating black hole and quintessence

We discuss spherically symmetric exact solutions of the Einstein equations for quintessential matter surrounding a black hole, which has an additional parameter (ω) due to the quintessential matter, apart from the mass (M). In turn, we employ the Newman−Janis complex transformation to this spherical quintessence black hole solution and present a rotating counterpart that is identified, for $\alpha = -e^2 \neq 0$ and $\omega = 1/3$, exactly as that of the Kerr−Newman black hole, and as that of the Kerr black hole when $\alpha = 0$. Interestingly, for a given value of parameter ω, there exists a critical rotation parameter ($a = a_E$), which corresponds to an extremal black hole with degenerate horizons, while for $a < a_E$, it describes a non-extremal black hole with Cauchy and event horizons, and no black hole for $a > a_E$. We find that the extremal value of a_E is also influenced by the parameter ω and so is the *ergoregion*.

Shapes of rotating nonsingular black hole shadows

It is believed that the curvature singularities are a creation of general relativity and hence, in the absence of a quantum gravity, models of nonsingular black holes have received significant attention. We study the shadow (apparent shape), an optical appearance because of its strong gravitational field, cast by a non-singular black hole, which is characterized by three parameters, i.e., mass (M), spin (a), and a deviation parameter (k). The black hole under consideration is a generalization of the Kerr black hole that can be recognized asymptotically ($r >> k, k > 0$) explicitly as the Kerr-Newman black hole, and in the limit $k \to 0$ as the Kerr black hole. It turns out that the shadow of a non-singular black hole is a dark zone covered by a deformed circle. Interestingly, it is seen that the shadow of a black hole is affected due to the parameter k. Indeed, for a given a, the size of a shadow reduces as the parameter k increases, and the shadow becomes more distorted as we increase the value of the parameter k when compared with the analogous Kerr black hole shadow. We also investigate, in detail, how the ergoregion of a black hole is changed due to the deviation parameter k. This work has been done in collaboration with Muhammed Amir.

Sarbari Guha

Particle motion and perturbed dynamical system in warped product spacetimes

We have used the dynamical systems analysis to study the dynamics of a five-dimensional universe in the form of a warped product spacetime with a spacelike dynamic extra dimension. We have decomposed the geodesic equations to get the motion along the extra dimension and have studied the associated dynamical system when the cross-diagonal element of the Einstein tensor vanishes, and also when it is non-vanishing. Introducing the concept of an energy function along the phase path in terms of the extra-dimensional co- ordinate, we have examined how the energy function depends on the warp factor. The energy function serves as a measure of the amount of perturbation of geodesic paths along the extra dimension in the region close to the brane. Then we studied the geodesic motion under a conventional metric perturbation in the form of homothetic motion and conformal motion, and examined the nature of critical points for a Mashhoon-Wesson-type metric, for timelike and null geodesics when the cross-diagonal term of the Einstein tensor vanishes. Finally, we investigated the motion for null and timelike geodesics under the condition when the cross-diagonal element of the Einstein tensor is non-vanishing and examined the effects of perturbation on the critical points of the dynamical system.

K. Indulekha

Possible density dependent local variations in the IMF

Systematic variations of the IMF are being explored recently. In the case of galaxies with non-standard IMFs, such non-universality of the IMF can affect their relative position with respect to the Kennicutt Schmidt Law between the gas surface density and the SFR, wherein the SFR is observationaly determined assuming a standard IMF. In this context, using a toy model, we have explored the impact of changes in the slope of the IMF, on estimates of the Star Formation Rate (SFR) that are made from radiation that is produced by processes that depend on the ionizing radiation that is produced by stars. It is found that wherein the SFR tracer flux is linearly dependent on the ionizing flux from the stars, the estimated SFR is increased compared to the actual if the slope of the IMF is flatter compared to the universal IMF that enters into the relation connecting the observed flux and the SFR, and decreased if it is steeper. The SFR in a cluster is likely to be over-estimated by $\sim$ 1-2 dex if the actual IMF of the cluster has a flatter slope ($\sim$1.3) and under-estimated by $\sim$1-2 dex for a cluster with a steeper slope ($\sim$ 3.3). This work has been done in collaboration with Remya Nair and Arundhathy.

Deepak Jain

Revisiting dark energy models using differential ages of galaxies

We use a test based on the differential ages of galaxies for distinguishing the dark energy models. As proposed by Jimenez and Loeb, relative ages of galaxies can be used to put constraints on various cosmological parameters. In the same vein, we reconstruct $H_0\frac{dt}{dz}$ and its derivative $H_0\frac{d^2t}{dz^2}$ using a model independent technique called non-parametric smoothing. Hence, for reconstruction of this quantity, we use the most recent $H(z)$ data. Further, we calculate $H_0\frac{dt}{dz}$ and its derivative for several models like Phantom, Einstein de Sitter (EdS), ΛCDM, Chevallier-Polarski-Linder (CPL) parametrization, Jassal-Bagla-Padmanabhan (JBP) parametrization and Feng-Shen-Li-Li (FSLL) parametrization. We check the consistency of these models with the results of reconstruction obtained in model independent way from the data. It is observed that $H_0\frac{dt}{dz}$ as a tool is not able to distinguish between the ΛCDM, CPL, JBP and FSLL parametrizations but as expected EdS and Phantom models show noticeable deviation from the reconstructed results. Further, the derivative of $H_0\frac{dt}{dz}$ for various dark energy models is more sensitive at low redshift. It is observed that the FSLL model is not consistent with the reconstructed results at redshifts less than 0.5, however, the ΛCDM model is in concordance with the 3σ region of the reconstruction. This work has been done in collaboration with N. Rani, S. Mahajan, A. Mukherjee and M. Biesiada.

Constraining cosmic curvature by using age of galaxies and gravitational lenses

We use two model-independent methods to constrain the curvature of the universe. In the first method, we study the evolution of the curvature parameter (Ω_{0k}) with redshift by using the observations of the Hubble parameter and transverse comoving distances obtained from the age of galaxies. Secondly, we also use an indirect method based on the mean image separation statistics of gravitationally lensed quasars. The basis of this methodology is that the average image separation of lensed images will show a positive, negative or zero correlation with the source redshift in a closed, open or flat universe respectively. In order to smoothen the datasets used in both the methods, we use a non-parametric method namely, Gaussian Process (GP). Finally from first method, we obtain $\Omega_{0k} = 0.025 \pm 0.57$ for a presumed flat universe while the cosmic curvature remains constant throughout the redshift region $0 < z < 1.37$ which indicates that the universe may be homogeneous. Moreover, the combined result from both the methods suggests that the universe is marginally closed. However, a flat universe can be incorporated at 3σ level. This work has been done in collaboration with A. Rana, S. Mahajan and A. Mukherjee.

Sanjay Jhingan

Spherical and non-spherical models of primordial black hole formation: Exact solutions

We construct spacetimes, which provide spherical and non-spherical models of black hole formation in the flat Friedmann-Lemaitre-Robertson-Walker (FLRW) universe with the Lemaitre-Tolman-Bondi solution and the Szekeres quasispherical solution, respectively. These dust solutions may contain both shell-crossing and shell-focusing naked singularities. These singularities can be physically regarded as the breakdown of dust description, where strong pressure gradient force plays a role.We adopt the simultaneous big bang condition to extract a growing mode of adiabatic perturbation in the flat FLRW universe. If the density perturbation has a sufficiently homogeneous central region and a sufficiently sharp transition to the background FLRW universe, its central shell-focusing singularity is globally covered. If the density concentration is sufficiently large, no shell-crossing singularity appears, and a black hole is formed. If the density concentration is not sufficiently large, a shell-crossing singularity appears. In this case, a large dipole moment significantly advances shell-crossing singularities and they tend to appear before the black hole formation. In contrast, a shell-crossing singularity unavoidably appears in the spherical and non-spherical evolution of cosmological voids. The present analysis is general and applicable to cosmological non-linear structure formation described by these dust solutions. This work has been done in collaboration with Tomohiro Harada.

Primordial black hole formation in the matter-dominated phase of the universe

We investigate primordial black hole formation in the matter-dominated phase of the universe, where non-spherical effects in gravitational collapse play a crucial role. This is in contrast to the black hole formation in a radiation dominated era. We apply the Zel'dovich approximation, Thorne's hoop conjecture, and Doroshkevich's probability distribution and subsequently derive the production probability β_0 of primordial black holes. The numerical result obtained is applicable even if the density fluctuation σ at horizon entry is of the order of unity. For $\sigma \ll 1$, we find a semi-analytic formula $\beta_0 \simeq 0.05556 \sigma^5$, which is comparable to the Khlopov-Polnarev formula. We find that the production probability in the matter-dominated era is much larger than that in the radiation-dominated era for $\sigma \lesssim 0.05$, while they are comparable with each other for $\sigma \gtrsim 0.05$. We also discuss how σ can be written in terms of primordial curvature perturbations. This work has been done in collaboration with Tomohiro Harada, Chul-Moon Yoo, Kazunori Kohri and Ken-ichi Nakao.

Md. Mehedi Kalam and Sk Monowar Hossein

Possible radii of compact stars: A relativistic approach

We are trying to give a generalized metric solution for compact stars. In this work, the inner structure of compact stars is checked from theoretical (by using Heinz IIa metric) as well as observational points of view. Here, we determine the possible radii of six compact stars: two binary millisecond pulsars, namely PSR J 1614-2230 and PSR J1903+327, and four X-ray binaries, namely Cen X-3, SMC X-1, Vela X-1 and Her X-1. Interestingly, we see that density of the star does not vanish at the boundary though it is maximum at the centre, which implies that these compact stars may be treated as strange stars rather than neutron stars. We propose a stiff equation of state (EoS) relating to pressure with matter density. We also obtain compactness and surface redshift, and compare it with the recent observational data. This work has been done in collaboration with Sajahan Molla.

Relativistic model of neutron stars in X-ray binary

In this work, we study the inner structure of some neutron stars by using the Heint IIa metric. We calculate the probable radii, compactness and surface redshift (from mass function graph) of five neutron stars (X-ray binaries) namely 4U 1538-52, LMC X-4,4U 1820-30, 4U 1608-52, EXO 1745-248. Here, we propose a stiff equation of state (EoS) of matter distribution, which relates pressure with matter density. Finally, we draw attention to the fact that the model described by Heint IIa is also useful to study some strange stars depending upon the choice of the parameter. This work has been done in collaboration with Rabiul Islam and Sajahan Molla.

Ram Kishor

Linear stability of equilibrium points in the restricted three body problem with perturbations

We have considered the well known restricted three body problem under the influence of perturbations in the form of radiation pressure and lack of sphericity of the primaries, respectively. We are interested to analyse the linear stability in case of three main resonances and hence, effect of perturbations on the stability regions. In order to achieve the goal, first, we have determined triangular equilibrium point then examined its linear stability and found that points are stable for the mass ratio $0 < \bar{\mu_c} < 0.0396478$, in the presence of perturbations. Perturbed mass ratio for three main resonance cases is obtained and noticed that it is increasing function of radiation pressure but it decreases with respect to oblateness. It is also observed that stability region expands with radiation pressure, in the presence and absence of oblateness but it contracts with oblateness. Again, effects of perturbations are analyzed and found that they affect the motion of restricted mass significantly in space. Results are helpful to study more generalized problem in the presence of some other type of perturbations such as P-R drag and solar wind drag, etc.

The linear stability of collinear equilibrium points and resonances

The stability properties, dynamical processes and factors affecting these are very important aspects to describe the behaviour of a dynamical system, because these play a significant role in the study of their past evolution. We discuss about the existence of collinear equilibrium points, their computation and stability analysis in the Chermnykh-Like problem un- der the influence of perturbations in the form of radiation pressure, oblateness and a disc. In the presence of the disc, there exists a new collinear equilibrium point in addition to the three points of the classical problem. We examine the linear stability of the collinear equilibrium points with respect to disc outer radius b instead of mass parameter μ, and it is found that all the collinear equilibrium points are unstable except L_3, which is stable for b $\in$(1.3312,1.5275) provided that remaining parameters are fixed. Further, we obtain stability regions and perturbed mass ratio in the case of three main resonances for L_3 under appropriate approximations. We analyze the effect of the perturbations numerically and it is observed that they significantly affect the motion of infinitesimal mass. The results are limited up to the regular symmetric disc and the radiation effect of the bigger primary but further it can be extended for more generalized cases. This work has been done in collaboration with Badam Singh Kushvah.

Nagendra Kumar

Propagation and damping of slow MHD waves in a flowing viscous coronal plasma

Since the launch of SOHO and TRACE, many observational evidences for the occurrence of slow magneto-acoustic waves in solar atmosphere have been detected. The propagating waves have been detected in sunspots, plumes and in loop footpoint regions, while standing slow waves have been found in hot coronal loops. Ground and space born satellite observations have confirmed that the solar and space plasmas are always dynamic, showing steady flow. Therefore, all the theoretical models should include the presence of an equilibrium flow. We have studied the propagation of slow MHD waves in a flowing viscous solar coronal plasma, and numerically solved the MHD equations by MacCormack method to examine the effect of steady flow on the damping of slow MHD waves in viscous solar coronal plasma. The authors have run the simulation for $0 \leq z \leq 0.5$ with 1001 grid points and presented temporal evolution of velocity and density perturbations in viscous solar plasma for different values of Mach number in both forward (parallel) and backward (anti parallel) flows. We observed that amplitude of velocity perturbation and damping time of slow waves decrease with the increase in the value of Mach number. Flow causes a phase shift in the perturbed velocity amplitude and an increase in wave period. The damping of slow waves in flowing viscous plasma is stronger than the damping of waves in viscous plasma. Slow wave in backward flow damps earlier than the wave in forward flow. This work has been done in collaboration with Anil Kumar and K. Murawski.

Suresh Kumar

Probing the interaction between dark matter and dark energy in the presence of massive neutrinos

We consider the possibility of an interaction in the dark sector in the presence of massive neutrinos, and study the observational constraints on three different scenarios of massive neutrinos using the most recent CMB anisotropy data in combination with type Ia supernovae, baryon acoustic oscillations, and Hubble parameter measurements. When a sterile neutrino is introduced in the interacting dark sector scenario in addition to the standard model prediction of neutrinos, we find that the coupling parameter, characterizing the interaction between dark matter and dark energy, is non-zero at 2σ confidence level. The interaction model with sterile neutrino is also found to be a promising one to alleviate the current tension on Hubble constant. We do not find the evidence for a coupling in the dark sector when the possibility of a sterile neutrino is discarded. This work has been done in collaboration with Rafael C. Nunes.

Determining the Hubble constant from Hubble parameter measurements

We use 28 Hubble parameter, H(z), measurements at intermediate redshifts $0.07 < z < 2.3$ to determine the present-day Hubble constant H_0 in four cosmological models. We measure $H_0 = 68.3^{+2.7}_{-2.6}, 68.4^{+2.9}_{-3.3}, 65.0^{+6.5}_{-6.6}$ and $67.9^{+2.4}_{-2.4}$ km s^{-1} Mpc $^{-1}$ (1σ errors) in the ΛCDM (spatially flat and non-flat), ωCDM and ϕCDM models respectively. These measured H_0 values are more consistent with the lower values determined from recent cosmic microwave background and baryon acoustic oscillation data, as well as with that found from a median statistics analysis of Huchra's compilation of H_0 measurements, but include the higher local measurements of H_0 within the 2σ confidence limits. This project has been completed in collaboration with Bharat Ratra.

V.C. Kuriakose

Thermodynamics of charged Lovelock: AdS black holes

We investigate the thermodynamic behaviour of maximally symmetric charged, asymptotic AdS black hole solutions of Lovelock gravity. We explore the thermodynamic stability of such solutions by the ordinary method of calculating the specific heat of the black holes and investigating its divergences which signal second-order phase transitions between black hole states. We then utilize the methods of thermodynamic geometry of black hole spacetimes in order to explain the origin of these points of divergence. We calculate the curvature scalar corresponding to a Legendre invariant thermodynamic metric of these spacetimes and find that the divergences in the black hole specific heat correspond to singularities in the thermodynamic phase space. We also calculate the area spectrum for large black holes in the model by applying the Bohr-Sommerfeld quantization to the adiabatic invariant calculated for the spacetime. This work has been done in collaboration with C. B. Prasobh and Jishnu Suresh.

Quasi normal modes and P-V criticallity for scalar perturbations in a class of dRGT massive gravity around black holes

We investigate black holes in a class of dRGT massive gravity for their quasi normal modes (QNMs) for neutral and charged ones using Improved Asymptotic Iteration Method and their thermodynamic behaviour. The QNMs are studied for different values of the massive parameter m_g for both neutral and charged dRGT black holes under massless scalar perturbation. As m_g increases, the magnitude of the quasi normal frequencies are found to be increasing. The results are also compared with the Schwarzchild de Sitter case. P-V criticallity of the aforesaid black holes under massless scalar perturbation in the de Sitter space are also studied. It is found that the thermodynamic behaviour of a neutral black hole shows no physically feasible phase transition, while a charged black hole shows a definite phase transition. This work has been done in collaboration with P. Prasia.

Badam Singh Kushvah

The effects of oblateness and solar radiation pressure on halo orbits in the photogravitational Sun-Earth system

In this work, we construct a third-order analytic approximate solution using the Lindstedt-Poincare method in the photogravitational circular restricted three body problem, considering the Sun as a radiating source and the Earth as an oblate spheroid for computing halo orbits around the collinear Lagrangian points L1 and L2 . Further, the well-known differential correction and continuation schemes are used to compute halo orbits and their families numerically. The effects of solar radiation pressure and oblateness on the orbit are studied around both Lagrangian points. It is noticed that time period of the halo orbit increases around L1 and L2 accounting oblateness of the Earth and solar radiation pressure of the Sun. It is also found that stability of halo orbits is a weak function of the out-of-plane amplitude and mass reduction factor. This work has been done in collaboration with Vineet K. Srivastava and Jai Kumar.

Regularization of circular restricted three-body problem accounting radiation pressure and oblateness

We apply a time-and space-coordinate transformation, commonly known as the Kustaanheimo-Stiefel (KS)-transformation, to reduce the order of singularities arising due to the motion of an infinitesimal body in the vicinity of a smaller primary in the three-body system. In this work, the Sun-Earth system is considered, assuming the Sun to be a radiating body and the Earth as an oblate spheroid. The study covers motion around collinear Lagrangian L1 and L2 points. Numerical computations are performed for both regularized and non-regularized equations of motion and results are compared for non-periodic as well as periodic motion. In the transformed space, time is also computed as a function of solar radiation pressure (q) and oblateness of the Earth (A2). The two parameters (q,A2) have a significant impact on time in the transformed space. It is found that KS-regularization reduces the order of the pole from five to three at the point of singularity of the governing equations of motion. This work has been done in collaboration with Vineet K. Srivastava and Jai Kumar.

Manzoor A. Malik

Low-ℓ power suppression in punctuated inflation

Motivated by Planck confirmation of an anomalously low value of the CMB temperature fluctuations up to multipole $\ell < 40$, we try to explain such feature by investigating case of punctuated inflation scenario. This form of inflation potential is inspired by Minimal Super-symmetric Standard Model (MSSM), wherein suppression of curvature perturbation power at large scales is produced by introducing period of fast-roll phase of the inflation sandwiched between two stages of slow-roll phase.

We apply Markov Chain Monte Carlo analysis to determine posterior distribution and the best fit values of the model parameters using recent WMAP9 and Planck data. We show that WMAP9 and Planck results are consistent with each other, and that with Planck data, we obtain tighter constraints for punctuated inflation parameters. We find that punctuated inflation leads to better fit in CMB data compared to simple power law model. The improvement in the fit to the WMAP9 data is $\Delta\chi^2 \sim 3.6$, and for Planck, the improvement is $\Delta\chi^2 \sim 5.4$. We find that *AIC* does not discriminate between punctuated inflation and simple power law model for WMAP9 data. However, for Planck data, we find that punctuated inflation is moderately preferred over a simple power law model. This work has been done in collaboration with Mussadiq Qureshi, Asif Iqbal and Tarun Souradeep.

Little evidence for entropy and energy excess beyond r_{500}: An end to ICM pre-heating?

Non-gravitational feedback affects the nature of the intra-cluster medium (ICM). X-ray cooling of the ICM and *in situ* energy feedback from AGN's and SNe, as well as *pre-heating* of the gas at epochs preceding the formation of clusters are proposed mechanisms for such feedback. While cooling and AGN feedbacks are dominant in cluster cores, the signatures of a preheated ICM are expected to be present even at large radii. To estimate the degree of pre-heating, with minimum confusion from AGN feedback/cooling, we study the excess entropy and non-gravitational energy profiles upto r_{200} for a sample of 17 galaxy clusters using joint data sets of *Planck* SZ pressure and *ROSAT/PSPC* gas density profiles. The canonical value of pre-heating entropy floor of $\gtrsim 300$ keV cm^2, needed in order to match cluster scalings, is ruled out at $\approx 3\sigma$. We also show that the feedback energy of 1 keV/particle is ruled out at 5.2σ beyond r_{500}. Our analysis takes both non-thermal pressure and clumping into account, which can be important in outer regions. Our results based on the direct probe of the ICM in the outermost regions do not support any significant pre-heating. This work has been done in collaboration with Asif Iqbal, Subhabrata Majumdar, Biman B. Nath, Stefano Ettori and Dominique Eckert.

Irom Ablu Meitei

Schechter function model for the QSO luminosity function from the SDSS DR7

Due to high luminosities and large redshifts, Quasi Stellar Objects (QSOs) can be used to probe the cosmological evolution of the Universe. The QSO evolution should also be closely related to the evolution of the host galaxy. The shape, normalization and evolution of the QSO luminosity function provides fundamental information about the QSOs and their evolution. The QSO luminosity function and its evolution with redshift should provide important clues about the demographics of the Active Galactic Nuclei (AGN) population and strong constraints on physical models and evolutionary theories of the AGN. In this work, we have studied the optical luminosity function of QSOs and its evolution with redshift using the Sloan Digital Sky Survey Data Release Seven (SDSS DR7). The observed QSO luminosity function is well fitted by a Schechter function model of the form: $\Phi(L_i)dL_i = \Phi^*(L_i/L_i^*)^\alpha exp(-L_i/L_i^*)d(L_i/L_i^*)$, where L_i^* is the break or characteristic luminosity with luminosity evolution characterized by a second order polynomial in redshift, $L_i^*(z) = L_i^*(0)10^{k_1 z + k_2 z^2}$. The best fit parameters are determined by using the Levenberg-Marquardt method of non-linear least square. This work has been done in collaboration with S. Ajitkumar Singh and K. Yugindro Singh.

Hameeda Mir

Effects of cosmological constant on clustering of galaxies

We analyse the effect of the expansion of the universe on the clustering of galaxies, and evaluate the configurational integral for interacting system of galaxies in an expanding universe by including effects produced by the cosmological constant. The gravitational partition function is obtained using this configuration integral. Thermodynamic quantities, specifically, Helmholtz free energy, entropy, internal energy, pressure and chemical potential are also derived. It is observed that they depend on the modified clustering parameter for this system of galaxies. It is also demonstrated that these thermodynamical quantities get corrected because of the cosmological constant. This work has been done in collaboration with Sudhakar Upadhyay, Mir Faizal and Ahmed Farag Ali.

Hemwati Nandan

Null geodesics in a magnetically charged stringy black hole spacetime

We study the null geodesics of a four-dimensional magnetic charged black hole spacetime arising in string theory. The behaviour of effective potential in view of the different values of black hole parameters are analysed in the equatorial plane. The possible orbits for null geodesics are also discussed in view of the different values of the impact parameter. We have also calculated the frequency shift of photons in this spacetime. The results are compared to those obtained for the electrically charged stringy black hole spacetime and the Schwarzschild black hole spacetime in general relativity. This work has been done in collaboration with Ravi Shankar Kuniyal, Rashmi Uniyal and K. D. Purohit.

Dyonic string-like solution in a non-Abelian gauge theory with two potentials

Axially symmetric dyon solutions of a non-Abelian gauge theory model with two potentials are sought. While seeking axially symmetric (flux tube like solutions) for the model, we stumbled upon an exact solution which represents an infinite string-like dyonic configuration with cylindrical symmetry. This work has been done in collaboration with Buddhi Vallabh Tripathi and K. D. Purohit.

Biswajit Pandey

How much a galaxy knows about its large-scale environment? An information theoretic perspective

The small-scale environment characterized by the local density is known to play a crucial role in deciding the galaxy properties, but the role of large-scale environment on galaxy formation and evolution still remain a less clear issue. We propose an information theoretic framework to investigate the influence of large-scale environment on galaxy properties and apply it to the data from the Galaxy Zoo project which provides the visual morphological classifications of ~ 1 million galaxies from the Sloan Digital Sky Survey. We find a non-zero mutual information between morphology and environment, which decreases with increasing length scales, but persists throughout the entire length scales probed. We estimate the conditional mutual information and the interaction information between morphology and environment by conditioning the environment on different length scales and find a synergic interaction between them, which operates upto at least a length scales of $\sim 30\,h^{-1}$ Mpc. Our analysis indicates that these interactions largely arise due to the mutual information shared between the environments on different length scales.

Relating information entropy and mass variance to measure bias and non-Gaussianity

We relate the information entropy and the mass variance of any distribution in the regime of small fluctuations. We use a set of Monte Carlo simulations of different homogeneous and inhomogeneous distributions to verify the relation and also test it in a set of cosmological N-body simulations. We find that the relation is in excellent agreement with the simulations and is independent of number density and the nature of the distributions. We show that the relation between information entropy and mass variance can be used to determine the linear bias on large scales and detect the signatures of non-Gaussianity on small scales in galaxy distributions.

S.K. Pandey

Optical and infrared imaging and spectral study of FR-I type radio galaxy: CTD 086 (B2 1422 + 26B)

Main focus was on isophote shape analysis, dust and multiphase ISM and their physical coexistence, if any. The work comprised of analysis of multi-wavelength data for a sample of radio loud elliptical galaxies taken from the B2 sample. Besides observations at optical broad and narrow bands from 2m IGO telescope, as well as from 2m HCT Hanle, archival data from SDSS (ugriz), 2MASS (JHKs), WISE, Spitzer (mid-IR), XMM, CHANDRA (X-ray), GALEX (UV) and VLA, IRAM (radio) were used for the analysis. This work has been done in collaboration with Sheetal Sahu.

A fresh investigation on the isophote shapes of a well defined sample of early-type galaxies using their multi-wavelength data available in the archives of SDSS

The objective of this work is to examine clues as regards to the role of dust and other faint features in evolution of early-type galaxies. They have selected a sample of lenticular galaxies from the archives of HST to carry out a detailed analysis of central (nuclear) regions of lenticular galaxies with the aim to explore possible correlation between pseudo and classical bulges in this class of galaxies. This work has been done in the collaboration with Amit Tamrakar, Sudhanshu Barway and Mahendra Verma.

P.N. Pandita

Measuring the trilinear neutral Higgs Boson couplings in the minimal supersymmetric standard model at e^+e^- colliders in the light of the discovery of a Higgs Boson

We consider the measurement of the trilinear couplings of the neutral Higgs Bosons in the minimal supersymmetric standard model (MSSM) at a high energy e^+e^- linear collider in the light of the discovery of a Higgs Boson at the CERN Large Hadron Collider (LHC). We identify the state observed at the LHC with the lightest Higgs Boson (h^0) of the MSSM, and impose the constraints following from this identification, as well as other experimental constraints on the MSSM parameter space. In order to measure trilinear neutral Higgs couplings, we consider different processes, where the heavier Higgs Boson (H^0) of the MSSM is produced in electron-positron collisions, which subsequently decays into a pair of lighter Higgs Boson. We identify the regions of the MSSM parameter space, where it may be possible to measure the trilinear couplings of the Higgs Boson at a future electron positron collider. A measurement of the trilinear Higgs couplings is a crucial step in the construction of the Higgs potential, and hence in establishing the phenomena of spontaneous symmetry breaking in gauge theories. This work has been done in collaboration with Charanjit K. Khosa.

Measuring the trilinear neutral Higgs Boson couplings in the MSSM at e^+e^- colliders

We consider the measurement of the trilinear couplings of the neutral Higgs Bosons (H^0, h^0) in the minimal supersymmetric standard model (MSSM) at a high energy e^+e^- linear collider in the light of the discovery of a Higgs Boson at the CERN Large Hadron Collider (LHC). We identify the state observed at the LHC with the lightest CP-even Higgs Boson of the MSSM. We implement this constraint, as well as all the other relevant experimental constraints, on the parameter space of the MSSM in order to study the feasibility of measuring the trilinear couplings of the neutral Higgs Bosons. For the measurement of trilinear couplings, we consider the multiple Higgs production processes. We delineate the regions of MSSM parameter space, where the trilinear couplings of the neutral Higgs Bosons could be measured at a high energy electron-positron collider.

Amit Pathak

Mid-infrared vibrational study of deuterium containing PAH variants

Polycyclic Aromatic Hydrocarbon (PAH) molecules have been long proposed to be a major carrier of 'Unidentified Infrared' (UIR) emission bands that have been observed ubiquitously in various astrophysical environments. These molecules can potentially be an efficient reservoir of deuterium. Once the infrared properties of the deuterium-containing PAHs are well understood, both experimentally and theoretically, the interstellar UIR bands can be used as a valuable tool to infer the cause of the deuterium depletion in the ISM. Density Functional Theory (DFT) calculations have been carried out on deuterium-containing ovalene variants to study the infrared properties of these molecules. These include deuterated ovalene, cationic deuterated ovalene, deuteronated ovalene and deuterated-deuteronated ovalene. We present a D/H ratio calculated from our theoretical study to compare with the observationally proposed D/H ratio. This work has been done in collaboration with M. Buragohain, P. J. Saare, T. Onaka and I. Sakon.

The distribution and kinematics of interstellar OVI in the Milky Way

We present the results of a survey of interstellar O VI absorption in the Milky Way (MW) towards 69 stars in the Large Magellanic Cloud (LMC) obtained with the Far Ultraviolet Spectroscopic Explorer (FUSE). The integrated MW O VI column densities log N(O VI) are in the range from 13.68 to 14.73 with a mean of 14.26+0.07 atoms cm^{-2} The O VI exponential scale height is found to be 2.28±1.06 kpc. The O VI column density correlates with the Doppler parameter b. The O VI velocity dispersion ranges from 14.0 to 91.6 with an average value of 62.7 km s^{-1}. These high values of velocity dispersion reveal the effect of turbulence, multiple velocity components and collision on broad O VI profiles. There is a significant variation of O VI column density on all scales studied (0.0025^o - 6.35^o). The smallest scale for which O VI column density variations has been found is $\triangle\theta \sim 9$ arcsec. Comparison of the O VI velocity profiles with Fe II indicates the presence of intermediate velocity cloud (IVC) and/or high velocity cloud (HVC) components in the O VI absorption. This work has been done in collaboration with R. Sarma, J. Murthy and J. K. Sarma.

Madhav K. Patil

Detection of a pair of prominent X-ray cavities in Abell 3847

The results obtained from the detailed analysis of a deep Chandra observation of the bright FRII radio galaxy 3C 444 in Abell 3847 cluster have been presented. A pair of huge X-ray cavities are detected along the north and south directions from the centre of 3C 444. X-ray and radio images of the cluster reveal peculiar positioning of the cavities and radio bubbles. The radio lobes and X-ray cavities are apparently not spatially coincident and exhibit offsets by $\sim$ 61 and 77 kpc from each other along the north and south directions respectively. Radial temperature and density profiles reveal the presence of a cool core in the cluster. Imaging and spectral studies showed the removal of substantial amount of matter from the core of the cluster by the radio jets. A detailed analysis of the temperature and density profiles showed the presence of a rarely detected elliptical shock in the cluster. Detection of inflating cavities at an average distance of $\sim$ 55 kpc from the centre implies the central engine feeds a remarkable amount of radio power ($\sim 6.3 \times 10^{44}$ erg/s) into the intra-cluster medium over $\sim 10^8$ yr, the estimated age of cavity. The cooling luminosity of the cluster was estimated to be $\sim 8.30 \times 10^{43}$ erg/s, which confirms that the AGN power is sufficient to quench the cooling. Ratios of mass accretion rate to Eddington and Bondi rates were estimated to be $\sim$ 0.08 and 3.5×10^4, respectively. This indicates that the black hole in the core of the cluster accretes matter through chaotic cold accretion. This work has been done in collaboration with Nilkanth D. Vagshette, Sachindra Naik and Satish S. Sonkamble.

AGN-driven perturbations in the intracluster medium of the cool-core cluster ZwCl 2701

We present the results obtained from a total of 123 ks X-ray (Chandra) and 8 h of 1.4 GHz radio (Giant Metrewave Radio Telescope) observations of the cool-core cluster ZwCl 2701 (z = 0.214). These observations showed the presence of an extensive pair of ellipsoidal cavities along the east and west directions within the central region < 20 kpc. Detection of bright rims around the cavities suggested that the radio lobes displaced X-ray-emitting hot gas forming shell-like structures. The total cavity power (mechanical) that directly heated the surrounding gas and cooling luminosity of the cluster were estimated to be $\sim 2.27 \times 10^{45}$ erg/s and 3.5×10^{44} erg/s respectively. Comparable values of cavity power and cooling luminosity of ZwCl 2701 suggested that the mechanical power of the active galactic nuclei (AGN) outburst is large enough to balance the radiative cooling in the system. The star formation rate derived from the Hα luminosity was found to be $\sim 0.60\ M_\odot$/yr, which is about three orders of magnitude lower than the cooling rate of $\sim 196\ M_\odot$/yr. Detection of the floor in entropy profile of ZwCl 2701 suggested the presence of an alternative heating mechanism at the centre of the cluster. Lower value of the ratio (10^{-2}) between black hole mass accretion rate and Eddington mass accretion rate suggested that launching of jet from the super massive black hole is efficient in ZwCl 2701. However, higher value of ratio ($\sim 10^3$) between black hole mass accretion rate and Bondi accretion rate indicated that the accretion rate required to create cavities is well above the Bondi accretion rate. This work has been done in collaboration with Nilkanth D. Vagshette, Satish S. Sonkamble and Sachindra Naik.

Bikash Chandra Paul

A class of relativistic solutions for compact cold stars with strange matter in a pseudo-spheroidal spacetime

The equation of state (EOS) of matter in a compact object, which is at extreme condition, is not yet known definitely. Considering strange matter equation of state, $p = \frac{1}{3}(\rho - 4B)$, where ρ, p and B are energy density, pressure and MIT Bag parameter respectively, as used in high energy nuclear model, stellar models are obtained. Using a pseudo-spheroidal geometry, described by Vaidya-Tikekar metric for anisotropic stellar model, we explore models of star, where B varies with the energy density (ρ) inside the compact object. The density dependent B is determined at different anisotropy. It is noted that although B varies with anisotropy inside the star, finally at the surface, it attains a value which is independent of the anisotropy. B is found to increase with an increase in anisotropy for a given compactness factor (M/b) and spheroidicity (λ). For a star with given mass and radius, we note that B increases with the increase in λ, and finally at large λ, it attains a constant. The EoS obtained here from geometrical consideration with allowed B value was found the same to that one obtains from micro-physics. The stability of the stellar models for compact stars with anisotropy in hydrostatic equilibrium is also studied. The work has been done in collaboration with P. K. Chattopadhyay.

Observational constraints on EoS parameters of emergent universe

Emergent universe model is studied using recent observational data of the background as well as the growth tests. It has been shown that a flat emergent universe scenario may be obtained in general theory of relativity with a non-linear equation of state: $p = A\rho - B\rho^{1/2}$, where A and B are constants. The choice of A determines the universe with three different types of fluid. In this work we choose A = 0, and analyse the cosmological model. Considering the Wang-Steinhardt ansatz for growth index (γ) and growth function, $f = \Omega_m^\gamma(a)$, the best-fit values of the EoS and growth parameters are then determined making use of chi-square minimization technique. The best-fit values are then used to determine the range of value of the present density (Ω_m) and Hubble parameter (H_0). Finally, the evolution of the growth function f, growth index γ, state parameter Ω, and deceleration parameter (q) for different redshift parameter z are investigated. The late accelerating phase of the universe in the EU model is found to be satisfactory. This work has been done in collaboration with Prasenjit Thakur.

Ninan Sajeeth Philip

Big data and astronomy

Automated classification and data analysis have been widely used in astrophysical problems over the past few decades. However, most of the tools and the data were of finite size. Though machine learning tools were used for producing catalogues based on known, labeled, celestial objects, they all used a dozen or less extracted features and simple algorithms for their creation. However, the situation has dramatically changed over the past few years when we became capable of storing, retrieving and analysing huge volumes of data of heterogeneous nature. The rate of creation and the demand for analysis has put great pressure on data scientists to invent new formats that did not require the popular table or similar structures for data storage. Hadoop, SciDB and Spark are three popular platforms available today for working with bigdata. Many of them have tested libraries that can be readily ported to any specific application that involve large volumes of heterogeneous data. We have been involved in porting and designing existing bigdata tools to astrophysical problems. The noticeable advantage of bigdata approach from traditional feature based learning systems is that it is able to identify features and learn on it's own without an explicit specification of the significant features. The obvious features one would use to separate them would be based on the differences in their morphologies.

The study of UV and X-ray variability of NLS1 Ark 564 galaxy

This study analysed the relationship between UV and X-ray variability of Ark 564 observed that X-ray reprocessing in these galaxies depends more on the geometry of the corona rather than the X-ray luminosity of the source. In torus covering factor study of type 1 AGN, the correlations, along with simulations suggest that the Eddington ratio is the major driver in the evolution of the covering factors, rather than the bolometric luminosity. The transient classification on LIGO used a hybrid method for classification of short duration transients seen in gravitational wave data using both supervised and unsupervised machine learning techniques. The study was done on simulated, hardware injections and LIGO science run (O1) data to identify the transients with an overall accuracy of 98 %. Also, the episodic outflows study lead to the discovery of signatures of a previously hypothesised magnetic pressure driven outflow mechanism during the high accretion phase of a protoplanetary disc system around V899 Monoceros. This discovery was done using the 11-m SALT telescope. All these will have more challenging counterparts in the bidata framework as upcoming giant telescopes and the volumes of data they produce have to be processed and analysed in real time. This work has been done in collaboration with Savithri H. Ezhikode, Gulab Chand Dewangan, Ranjeev Misra, Shruti Tripathi and Ajit Kembhavi.

Anirudh Pradhan

Emergence and oscillation of cosmic space by joining M1-branes

It was recently proposed by T. Padmanabhan [arXiv:1206.4916 [hep-th]] that the difference between the number of degrees of freedom on the boundary surface and the number of degrees of freedom in a bulk region leads to the expansion of the universe. Now, a natural question arises: How this model could explain the oscillation of universe between contraction and expansion branches? We try to address this issue in the framework of BIonic system. In this model, M0-branes join to each other and give rise to a pair of M1-anti-M1-branes. The fields which live on these branes play the roles of massive gravitons that cause the emergence of a wormhole between them and formation of a BIon system. This wormhole dissolves into M1-branes and causes a divergence between the number of degrees of freedom on the boundary surface of M1 and the bulk leading to an expansion of M1-branes. When M1-branes become close to each other, the square energy of their system becomes negative and some tachyonic states emerge. To removes these states, M1-branes compact, the sign of compacted gravity changes, causing the arising of anti-gravity. In this case, branes get away from each other. By articulating M1-BIons, an M3-brane and an anti-M3-brane are created and connected by three wormholes forming an M3-BIon. This new system behaves like the initial system and by closing branes to each other, they compact, and by getting away from each other, they open. Our universe is located on one of these M3-branes, and by compacting M3-brane, it contracts, and by opening it, it expands. This work has been done in collaboration with Alireza Sepehri, Farook Rahaman, Salvator Capozziello and Ahmed Farag Ali.

Teleparallel loop quantum cosmology in a system of intersecting branes

Recently, some authors have removed the big bang singularity in teleparallel Loop Quantum Cosmology (LQC), and have shown that the universe may undergo a number of oscillations. We investigate the origin of this type of teleparallel theory in a system of intersecting branes in M-theory, in which the angle between them changes with time. This system is constructed by two intersecting anti-D8 branes, one compacted D4 brane and a D3 brane. These branes are built by joining M0 branes, which develop in decaying fundamental strings. The compacted D4 brane is located between two intersecting anti-D8 branes and glues to one of them. Our universe is located on the D3 brane, which wraps around the D4 brane from one end and sticks to one of the anti-D8 branes from the other one. In this system, there are three types of fields, corresponding to compacted D4 branes, intersecting branes and D3 branes. These fields interact with each other and make the angle between branes oscillate. By decreasing this angle, the intersecting anti-D8 branes approach each other, the D4 brane rolls, the D3 brane wraps around the D4 brane, and the universe contracts. By separating the intersecting branes and increasing the angle, the D4 brane rolls in the opposite direction, the D3 brane separates from it and the expansion branch begins. Also, the interaction between branes in this system gives us the exact form of the relevant Lagrangian for teleparallel LQC. This work has been done in collaboration with Alireza Sepehri, Aroonkumar Beesham and Jaume de Haro.

Farook Rahaman

The Finslerian wormhole models

We present models of wormhole under the Finslerian structure of spacetime. This is a sequel of our previous work, where we have constructed a toy model for compact stars based on the Finslerian spacetime geometry. In the present investigation, a wide variety of solutions are obtained that explore wormhole geometry by considering different choices for the form function and energy density. The solutions, like the previous work, are revealed to be physically interesting and viable models for the explanation of wormholes as far as the background theory and literature are concerned. This work has been done in collaboration with Nupur Paul, S. S. De, Saibal Ray, A. Banerjee and A. A. Usmani.

S. R. Rajesh

SEP events and wake region lunar dust charging with grain radii

Our lunar surface is exposed to all kinds of radiations from the Sun, since it lacks a global magnetic field. Like lunar surface, dust particles are also exposed to plasmas and UV radiation, and consequently they carry electrostatic charges. During Solar Energetic Particle events (SEPs), secondary electron emission plays a vital role in charging of lunar dusts. To study the lunar dust charging during SEPs on lunar wake region, we derived an expression for lunar dust potential, and analyzed how it varies with different electron temperatures and grain radii. Because of high energetic solar fluxes, secondary yield (δ) values reach up to 2.3 for 0.5 μm dust grain. We got maximum yield at an energy of 550 eV, which is in well agreement with lunar sample experimental observation (Anderegg et al., 1972). It is observed that yield value increases with electron energy, reaches to a maximum value and then decreases. During SEPs, heavier dust grains show larger yield values because of the geometry of the grains. On the wake region, the dust potential reaches up to -497 V for 0.5 μm dust grain. The electric field of these grains could present a significant threat to manned and unmanned missions to the Moon.

Shantanu Rastogi

Aerosol black carbon quantification in the central Indo-Gangetic Plain: Seasonal heterogeneity and source apportionment

Two years of aerosol spectral light absorption measurements, using filter based technique, from the central Indo-Gangetic plain (IGP), Gorakhpur (26.75 °N, 83.38°E, 85mamsl), are analyzed to study their seasonal behaviour and to quantify their magnitude in terms of absorbing aerosols loading and source speciation. Spectral absorption analysis reveals a four-fold enhancement in absorption in winter (W) and post-monsoon (PoM) seasons at UV wavelengths as compared to IR wavelengths on account of increased biomass burning aerosol contribution to total absorbing aerosol load. Aerosols from the biomass sources contribute $\sim$ 28% during W and PoM seasons as against $\sim$ 16% in pre-monsoon (PM) and monsoon (M) seasons to the total absorbing aerosol content. A mode shift in the distribution of the Absorption Angstrom exponent (α) from 1.3 to 1.6 from PM-M seasons to PoM-W seasons signifies change in source type of absorbing aerosols from fossil fuel to biomass burning and their relative source strength. Due to near stagnant wind conditions combined with shallow boundary layer height, where air masses travelling to the central IGP are confined to a smaller volume, in W and PoM seasons, local sources assume more prominence rather than long-range transport of aerosols. Long-term measurements of aerosols physicochemical and radiative properties from this measurement location will enhance our understanding of the complex aerosol system over the IGP and its climatic implications. This work has been done in collaboration with Aditya Vaishya, Prayagraj Singh and S. Suresh Babu.

Saibal Ray

Gravastar in f(R,T) gravity

We propose a unique stellar model under the f(R,T) gravity by using the conjecture of Mazur-Mottola (2001, 2004), which is known as gravastar and a viable alternative to the black hole as available in literature. This gravastar is described by the three different regions, viz., (i) Interior core region, (ii) Intermediate thin shell, and (iii) Exterior spherical region. The pressure within the interior region is equal to the constant negative matter density, which provides a repulsive force over the thin spherical shell. This thin shell is assumed to be formed by a fluid of ultra relativistic plasma and the pressure, which is directly proportional to the matter-energy density, and according to Zel'dovich's conjecture of stiff fluid (Zeldovich 1972), it does counter balance the repulsive force exerted by the interior core region. The exterior spherical region is completely vacuum and assumed to be de Sitter spacetime, which can be described by the Schwarzschild solution. Under this specification, we find out a set of exact and singularity-free solution of the collapsing star, which presents several other physically valid features within the framework of alternative gravity.

N C Rana: Life and his contributions in astrophysical science

Narayan Chandra Rana, a person with extraordinary potential from a remote village in Bengal, India, came into the limelight of the international scientific world through his exceptional talent, zeal and courage. In his very short life-span, he excelled not only into various branches of astrophysics, but also took a leading role in science popularization, text book writing, etc. In this project, life and works of that scientist of India have been discussed from multifarious viewpoints.

Anirban Saha and Sunandan Gangopadhyay

Resonant detectors of gravitational wave as a possible probe of the non-commutative structure of space

We report the plausibility of using quantum mechanical transitions, induced by the combined effect of gravitational waves (GWs) and non-commutative (NC) structure of space, among the states of a 2-dimensional harmonic oscillator, to probe the spatial NC geometry. The phonon modes excited by the passing GW within the resonant bar-detector or spherical detectors are formally identical to force harmonic oscillator and they represent a length variation of roughly the same order of magnitude as the characteristic length-scale of spatial non-commutativity estimated from the phenomenological upper bound of the NC parameter. With this motivation, we employ various GW wave-forms that are typically expected from possible astronomical sources. We find that the transition probablities are quite sensitive to the nature of polarization of the GW. We also elaborate on the particular type of sources of GW radiation from which one can induce such transitions. We speculate that this can be used as an effective probe of the spatial non-commutative structure when the quantum limit of sensitivity is achieved/surpassed in resonant bar/spherical detectors of GWs in the near future.

Sanjay Kumar Sahay

A communication efficient and scalable distributed data mining for the astronomical data

In 2020, $\sim$ 60PB of archived data will be accessible to the astronomers. But to analyze such a paramount data will be a challenging task. This is basically due to the computational model used to download the data from complex geographically distributed archives to a central site and then analyzing it in the local systems. Because the data has to be downloaded to the central site, the network BW limitation will be a hindrance for the scientific discoveries. Also analyzing this PB-scale on local machines in a centralized manner is challenging. In this, virtual observatory is a step towards this problem, however, it does not provide the data mining model (Zhang et al., 2004). Adding the distributed data mining layer to the VO can be the solution in which the knowledge can be downloaded by the astronomers, instead of the raw data, and thereafter astronomers can either reconstruct the data back from the downloaded knowledge or use the knowledge directly for further analysis. Therefore, in this work, we present Distributed Load Balancing Principal Component Analysis for optimally distributing the computation among the available nodes to minimize the transmission cost and downloading cost for the end user. The experimental analysis is done with Fundamental Plane (FP) data, Gadotti data and complex Mfeat data. In terms of transmission cost, our approach performs better than Qi, et al. and Yue, et al. The analysis shows that with the complex Mfeat data, $\sim$90% downloading cost can be reduced for the end user with the negligible loss in accuracy. This work has been done in collaboration with Aruna Govada.

An effective approach for classification of advanced malware with high accuracy

Combating malware is very important for software/systems security, but to prevent the software/systems from the advanced malware, viz. metamorphic malware is a challenging task, as it changes the structure/code after each infection. Therefore, in this work, we present a novel approach to detect the advanced malware with high accuracy by analyzing the occurrence of opcodes (features) by grouping the executables. These groups are made on the basis of our earlier studies that the difference between the sizes of any two malware generated by popular advanced malware kits, viz. PS-MPC, G2 and NGVCK are within 5 KB. On the basis of obtained promising features, we studied the performance of thirteen classifiers using N-fold cross-validation available in machine learning tool WEKA. Among these thirteen classifiers, we studied in-depth top five classifiers (Random forest, LMT, NBT, J48 and FT) and obtained more than $\sim 96.28\%$ accuracy for the detection of unknown malware, which is better than the maximum detection accuracy ($\sim 95.9\%$) reported by Santos, et al. (2013). In these top five classifiers, our approach obtained a detection accuracy of $\sim 97.95\%$ by the Random forest. This work has been done in collaboration with Ashu Sharma.

Asoke Kumar Sen

Laboratory photometry of regolith analogues: Effect of porosity

New laboratory phase curves are presented, to examine the effect of porosity on reflectance as a function of phase angle for grain size having dimension about half, twice and those larger than the illuminating wavelength. The experimental setup used for generating reflectance data is a goniometric device developed at the Department of Physics, Assam University, Silchar, India. Some of the well-documented samples having different sizes were chosen: alumina, olivine, basalt, rutile, chromite and iron. The sample surfaces were prepared with different porosities, in order to simulate natural regolith surface as much as possible. The wavelength of observation is 632.8 nm. A model based on the Radiative Transfer Equation is presented here to analyze and model the laboratory data. In the present modelling work, the empirical relation of Hapke, Mie theory and Henyey-Greenstein phase function are used. For particles having dimension about half, twice to the wavelength, Mie theory is used to calculate single scattering albedo. Although the Mie theory is insufficient for describing the scattering properties of particles larger than the wavelength, for such large particle single scattering albedo (SSA) is estimated through method of best fit. It has been found that the porosity has a distinguishable effect on reflectance. Also, the contribution of multiple scattering function for different porosity is examined. Further, the results demonstrate the light scattering properties of a diverse collections of regolith like samples. This work has been done in collaboration with A. Kar and Ranjan Gupta.

The effect of gravitation on the polarization state of a light ray

In the present work, detailed calculations have been carried out on the rotation of the polarization vector of an electromagnetic wave due to the presence of a gravitational field of a rotating body. This has been done using the general expression of Maxwell's equation in curved spacetime. Considering the far-field approximation (i.e., the impact parameter is greater than the Schwarzschild radius and rotation parameter), the amount of rotation of the polarization vector as a function of impact parameter has been obtained for a rotating body (considering Kerr geometry). The present work shows that the rotation of the polarization vector cannot be observed in the case of Schwarzschild geometry. This work also calculates the rotational effect when considering prograde and retrograde orbits for the light ray. Although the present work demonstrates the effect of rotation of the polarization vector, it confirms that there would be no net polarization of an electromagnetic wave due to the curved spacetime geometry in a Kerr field. This work has been done in collaboration with Tanay Ghosh.

T.R. Seshadri

Cosmic magnetogenesis in inflationary context

One of the issues with most scenarios of cosmic magnetogenesis in inflationary context is that the effective electic charge is very high at the beginning of inflation. We have investigated this problem and have constructed scenarios where this difficulty can be circumvented. The energy scales of inflation and the nature of reheating process in the post inflationary era have been investigated that will allow to solve this problem. This work has been done in collaboration with Ramkishor Sharma, Sandhya Jagannathan and Kandaswamy Subramanian.

Neutral Hydrogen structures during the epoch of reionization using fractal dimensions

From low-frequency experiments, the first detection of the 21 cm signal from reionization is expected soon. This is likely to be done by estimating the power spectrum, or equivalently the two-point correlation function, of the HI density field. The distribution of the ionized bubbles during the reionization epoch is expected to lead to a 21 cm signal that is highly non-Gaussian. Hence, the power spectrum, or equivalently, the two-point correlation function is insufficient to describe the distribution as a significant amount of information would be contained in the higher order correlations of the distribution. Using a semi-numeric simulation we have explored the generalized correlation dimension (or the Minkowski-Bouligand dimension) Dq as a diagnostic for understanding the nature of the HI distribution. This work has been completed in collaboration with Bidisha Bandyopadhyay and Tirthankar Roy Choudhury.

Ranjan Sharma

Charged compact stellar model in Finch-Skea spacetime

Making use of the Finch and Skea ansatz (*Class. Quantum Gravity* **6**, 467, 1989), we have presented a new class of solutions for a spherically symmetric compact stellar object, whose exterior spacetime is described by the Riessner-Nordström metric. The solution has been generated by assuming a specific charge distribution, and its relevance has been analyzed in the context of relativistic objects possessing a net charge. Effects of charge on the mass-radius ($M-R$) relationship of compact stars, in particular, has been probed. This work has been done in collaboration with B.S. Ratanpal, D.M. Pandya and S. Das.

A comparative study between EGB gravity and GTR by modelling compact stars

Studies of gravitational behaviour in higher dimensions have often been found to yield non-trivial and interesting results. A natural generalization of the GTR to higher dimensions is the Einstein-Gauss-Bonnet (EGB) gravity, in which the Lagrangian includes a second-order Lovelock term. To analyze stellar features in higher dimensions, we have extended the relativistic stellar model of Krori and Barua (*J. Phys. A* **8**, 508, 1975) by incorporating the higher dimensional curvature correction term of EGB gravity. They have shown that the Gauss-Bonnet coupling constant α might have non-negligible effects on the physical features of relativistic compact stars. The most notable feature of the study is that one can pack in more mass within a given radius in EGB gravity. This work has been done in collaboration with Piyali Bhar and Megan Govender.

Parijat Thakur

Investigating extra-solar planetary system Qatar-1 through transit observations

We have been working in the field of close-in transiting extra-solar planetary systems. The objective of the photometric follow-up observations is to improve the estimates of the physical and orbital parameters of the extra-solar planetary systems, as well as to refine the ephemeris for the orbital periods and mid-transit times required for the future transit observations. In addition to this, the photometric follow-up of transiting extra-solar systems allows them to estimate the mid-transit times to examine the transit timing variations (TTVs) with greater accuracies, which would lead to confirm the presence or absence of the additional low-mass planets in the extra-solar planetary systems. In order to pursue this project, they processed the three photometric follow-up transit data of Qatar-1 extra-solar planetary system observed from the 2-m Himalayan Chandra Telescope (HCT), using the standard procedures within IRAF. The differential photometry is performed to plot the light curve of Qatar-1 system for each transit events by employing the aperture photometry task 'phot' within IRAF. In order to have refine estimate of the ephemeris, they analyzed thirty eight light curves, which include three transit light curves of Qatar-1 system observed using HCT, twenty seven from the literatures and eight from the Exoplanet Transit Database (ETD). Using these thirty eight light curves, they refined the ephemeris for the orbital period and mid-transit time of this system. By employing these refined ephemeris, they estimate the calculated mid-transit time and then subtract it from the observed mid-transit time to generate (O-C) data for all the thirty eight epochs. To investigate the existence of TTVs, they plotted the (O-C) data as a function of epoch and then fitted the straight line of zero variation to the (O-C) data. For this fit, they obtained $X^2red = 1.12$, which indicates the null-TTV model. This result suggests that there is no evidence of TTVs, which allows them to conclude that there is no existence of additional planet in the Qatar-1 system. This work has been done in collaboration with Vineet Kumar Mannadey, Ing-Guey Jiang and D. K. Sahu.

Exploring the environment of accreting compact object with X-ray binaries

We have been working on the X-ray binaries to understand their physical nature and science surrounding them with the presently available archival data, and the analyzing tools from the various space telescopes such as XMM-Newton, Suzaku, Chandra and RXTE. In this project, the authors have been trying to probe the immediate vicinity of the strong gravity near the compact object, the accretion disk mechanism and the physics surrounding the coronal region of X-ray binaries. The relation between such two types of analysis will be a marginal tool to probe the coupling between the accretion disk and the hot coronal region. At present, they have analyzed the data of high mass black hole X-ray binary (HMXB) LMC X-1 taken by XMM-Newton in 2000 and 2002 and confirm the result of Alam, et al. (2014) that there is the presence of mHz QPO and iron line in the data taken in 2002. In addition to this, they have also analyzed the XMM-Newton data of LMC X-1 in 2014 and find no sign of QPO and broad iron line. This allows them to conclude that the source might have reached to its high-soft state (HSS) in the data taken in 2014. They are also very much curious about the first multi-wavelength Indian space observatory AstroSat due to its better spectral and timing resolutions, large effective area and broad band energy range, which can result in an excellent tool to investigate the X-ray binaries with higher accuracy. In collaboration with IUCAA, they are looking forward to use the data taken by the AstroSat for this study. This work has been done in collaboration with Swadesh Chand.

Arun Thampan

Fast spinning strange stars: Possible ways to constrain interacting quark matter parameters

For a set of equation of state (EoS) models involving interacting strange quark matter, characterized by an effective bag constant ($B_{\rm eff}$) and a perturbative QCD correction term (a_4), we construct fully general relativistic equilibrium sequences of rapidly spinning strange stars for the first time. Computation of such sequences is important to study milli-second pulsars and other fast spinning compact stars. Our EoS models can support a gravitational mass ($M_{\rm G}$) up to $\approx 3.0 M_\odot$ and a spin frequency (ν) up to $\approx$ 1250 Hz, and hence are fully consistent with measured $M_{\rm G}$ and ν values. This project reports the effects of $B_{\rm eff}$ and a_4 on measurable compact star properties, which could be useful to find possible ways to constrain these fundamental quark matter parameters, within the ambit of our EoS models. We confirm that a lower $B_{\rm eff}$ allows a higher mass. Besides, for known $M_{\rm G}$ and ν, measurable parameters, such as stellar radius, radius-to-mass ratio and moment of inertia, increase with the decrease of $B_{\rm eff}$. Our calculations also show that a_4 significantly affects the stellar rest mass and the total stellar binding energy. As a result, a_4 can have strong signatures in evolutions of both accreting and non-accreting compact stars, and the observed distribution of stellar mass and spin, orbital period and other source parameters. Finally, we compute the parameter values of two important pulsars, PSR J1614-2230 and PSR J1748-2446ad, which may have implications to probe their evolutionary histories, and for constraining EoS models. This work has been done in collaboration with Sudip Bhattacharyya, Ignazio Bombaci and Domenico Logoteta.

Online courses: Challenges and opportunities for education in India

Regular lecture courses fail to engage students for the reason that the courses are not "on demand". At the same time, an interactive session is important for understanding of the subject. Keeping this in mind, it becomes advantageous to have an accessible version of the course so that the students can reach out when ready. Together with the need for a fair system of evaluation in the continuous assessment, we have initiated a pilot online (hybrid) course in our department. The courses added, to begin with, are those that are computer based (Astrophysics Lab and C Programming Lab). However, with increasing sophistication, it is possible to bring some of the core courses to the online medium. Initial results show that students enjoy the medium, and furthermore, that the mechanism reduces (to some extent) the disparity in the knowledge in the class.

Paniveni Udayashankar

Supergranulation: A convective phenomenon

Presently studying the latitudinal variation of fractal dimension of supergranular convective cells. Fractal dimension is determined by the Area-Perimeter relation. Area of the supergranular cell is obtained by the parallel scans across the chosen supergranular cell. We have chosen a fiducial y-direction and performed velocity profile scans along the x-direction for all the pixel positions on the y-axis. In each such scan, the cell extent is said to be marked by the sum of the juxtaposed crest separated by a trough expected in the velocity scan. This set of data points was used to determine the area and hence, the perimeter of the supergranular cells. By using the software written in IDL, the perimeter is determined. Fractal dimension is obtained by using the relation P $\propto A^{D/2}$. Information on the latitude is also obtained by using IDL programme. The plot of latitude vs fractal dimension shows a symmetrical variation.

Fractal dimension of supergranulation

Fractal dimension is a valuable mathematical tool to quantify the complexity of geometrical structures. In the context of solar supergranulation, the network of convective cells observed on the solar photosphere, fractal dimension can reveal the dependence of the cell shape complexity on solar rotation, phase, magnetic activity level, and thereby provide insight into the underlying dynamics. This information can be useful for comparing observations with models. In particular, study of supergranular fractal dimension can shed light on the turbulence of the magneto-convective process that generates the magnetic structures. This work has been done in collaboration with G. Rajani, G. M. Sowmya, M. Yamuna and R. Srikanth.

A. A. Usmani

Structural and decay properties of $Z = 132, 138$ superheavy nuclei

We analyze the structural properties of $Z = 132$ and $Z = 138$ superheavy nuclei within the ambit of axially deformed relativistic mean-field framework with NL3* parametrization, and calculate the total binding energies, radii, quadrupole deformation parameter, separation energies, and density distributions. We also investigate the phenomenon of shape co-existence by performing the calculations for prolate, oblate and spherical configurations. For clear presentation of nucleon distributions, the two-dimensional contour representation of individual nucleon density and total matter density has been made. Further, a competition between possible decay modes such as α-decay, β-decay and spontaneous fission of the isotopic chain of superheavy nuclei with $Z = 132$ within the range $312 \leq A \leq 392$ and $318 \leq A \leq 398$, for $Z = 138$ is systematically analyzed within self-consistent relativistic mean-field model. From our analysis, we inferred that the α-decay and spontaneous fission are the principal modes of decay in majority of the isotopes of superheavy nuclei under investigation apart from β-decay as dominant mode of decay in $^{318-322}138$ isotopes. This work has been done in collaboration with Asloob A Rather, M. Ikram, Bharat Kumar and S. K. Patra.

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(c) BOOKS

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(d) SUPERVISION OF Ph.D. THESES

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5. **Ujjal Debnath** (2016) Title: *Consequences of dark energy in black hole and accelerating universe*, Indian Institute of Engineering Science and Technology, Shibpur.
Student: Bhadra Jhumpa.

6. **Ujjal Debnath** (jointly with **Shivendu Chakraborty**) (2016) Title: *Study of cosmological properties of the universe in higher dimension*, Indian Institute of Engineering Science and Technology, Shibpur.
Student: Ranjit Chayan.

7. **Ujjal Debnath** (jointly with **Ritabrata Biswas**) (2016) Title: *Study of gravitational collapse and dynamics of some dark energy models responsible for the recent cosmic acceleration,* Indian Institute of Engineering Science and Technology, Shibpur.
Student: Prabir Rudra.

8. **Sarbari Guha** (2017) *Title: On some investigations of cosmological solutions and geodesic motions in brane world scenario,* Jadavpur University.
Student: Pinaki Bhattacharya.

9. ***Anirudh Pradhan** (2016) Title: A study on homogeneous and inhomogeneous universe with reference to alternative theories of gravitation,* Sam Higginbothams Institute of Agriculture, Technology and Sciences, Allahabad.
Student: Anand Shanker Dubey.

10. **Farooq Rahaman** (2016) Title: *Study on some astrophysical objects in different* dimensional *spacetimes,* Jadavpur University.
Student: Piyali Bhar.

11. **Farooq Rahaman** (2016) Title: *Astrophysical phenomena in non-communicative geometry,* Jadavpur University.
Student: Umar Farooque Monda.

12. **T.R. Seshadri** (jointly with Shiv Sethi) (2016) Title: *Possible observational signatures and the effect of some exotic sources on cosmic reionization,* University of Delhi.
Student: Bidisha Bandyopadhyay.

13. **T.R. Seshadri** (jointly with **Anjan Ananda Sen**) (2016) Title: *Cosmology and particle physics from higher dimensional theories,* University of Delhi.
Student: Sampurnanand.

(e) AWARDS AND DISTINCTIONS

1. **Farooq Ahmad** was felicitated by the Hon'ble Governor of Jammu and Kashmir, N.N. Vohra, during the 34th meeting of the Astronomical Society of India, at the University of Kashmir, Srinagar, May 2016.

2. **Asis Kumar Chattopadhyay** has been selected as a Fellow of International Astrostatistics Association, 2016.

3. **Asis Kumar Chattopadhyay** has been elected as a member of International Statistical Institute, 2016.

4. **Asis Kumar Chattopadhyay** has been nominated as a Statistical Expert in task force committee for big data science in astrophysics, Government of India, 2017.

5. **Surajit Chattopadhay** was awarded the IAU Travel Grant (Partly), and INSA - ICSU Travel Grant (Partly), to participate in the IAU Symposium 324: New Frontiers in Black Hole Astrophysics at Cankarjev dom, Ljubljana, The Republic of Slovenia, May 2016.

6. **Sarbari Guha** was felicitated by St. Xavier's College, Kolkata on completion of 25 years of her service, January 2017.

7. **Badam Singh Kushvah** was presented Canara Bank Research Publication Award, ISM Dhanbad, 2016.

8. **Badam Singh Kushvah** has been sanctioned a grant for the project, titled "Efficient trajectory design for space missions", by SERB, Department of Science and Technology, Government of India.

9. **Anirudh Pradhan** was awarded the Bharat Ratna Dr. Abdul Kalam Gold Medal, during the 38th National Unity Conference on Individual Achievements and National Development at Bengaluru, by the Global Economic Progress and Research Association, October 2016.

10. **T.R. Seshadri** (with Hum Chand as the Co-PI) has been sanctioned a grant for the project, titled "Magnetic fields as probes of astrophysical phenomena", by SERB, Department of Science and Technology, Government of India.

Department of Physics and Astrophysics, University of Delhi

Coordinator: T.R. Seshadri, and Joint Coordinator: Harinder Pal Singh

Areas of Research

- Magnetogenesis in early universe
- Magnetic fields in galactic systems and inter-galactic region
- Cosmic reionization and 21 cm cosmology
- High energy physics in higher dimensional cosmology

Research Work

- While there are theories for the primordial generation of magnetic fields, no theory exist which is free from problems. One of the problems that plagues the theories of inflationary generation of magnetic fields is the strong coupling. The issue deals with the fact that in almost all such magnetogenesis models, the effective electric charge is very large in the beginning of inflation. At IRC, we have addressed this issue, and have been studying scenarios where this problem can be avoided.

- Using the technique of fractal dimension, the nature of neutral Hydrogen clouds at the epoch of reionization has been studied. Fractal characterization of inside-out model is very different from the outside-in model. This can be a probe to see the details of how reionization proceeded.

- Cosmic curvature of the Universe has been constrained using the ages of galaxies and gravitational lensing. It has been shown that the flat universe is consistent at a 3ó level. But the best fit line shows deviation from the flat universe prediction.

List of Publications

Akshay Rana, Deepak Jain, Shobhit Mahajan and Amitabha Mukherjee (2016), *Revisiting the distance duality relation using the non-parametric regression method*, JCAP, **7,** 26.

Bidisha Bandyopadhyay, Tirthankar Roy Choudhury and T. R. Seshadri (2017) *Studying neutral Hydrogen structures during the epoch of reionization using fractal dimensions*, MNRAS, **466(2),** 2302.

Akshay Rana, Deepak Jain, Shobhit Mahajan and Amitabha Mukherjee (2017) *Constraining cosmic curvature by using age of galaxies and gravitational lenses*, JCAP, **3,** 28.

Nisha Rani, Deepak Jain, Shobhit Mahajan, Amitabha Mukherjee and Marek Biesiada (2017) *Revisiting dark energy models using differential ages of galaxies*, JCAP, **3,** 5.

Ph.D. Theses

Title: *Cosmology and particle physics from higher dimensional theories.*
Student: Sampurnanand
Supervisors: T. R. Seshadri and Anjan Ananda Sen
(University of Delhi)

Title: *Possible observational signatures and the effect of some exotic sources on cosmic* reionization.
Student: Bidisha Bandyopadhyay_
Supervisors: T. R. Seshadri and Shiv K. Sethi
(University of Delhi)

Talks/Seminars

Noise kernel for self similar Tolman-Bondi metric: Fluctuations at Cauchy horizon by Seema Satin (IISER, Mohali).

Entanglement entropy, gravity and coherent states by Madhavan Varadharajan (RRI, Bengaluru).

Discovery of gravitational waves from GW150914 and its implications by Anuradha Gupta (IUCAA, Pune).

Black holes: Quantum information from quantum correlations by Kinjalk Lochan (IUCAA, Pune).

Spin dynamics in general relativity by Satish Kumar Saravanan (Lorentz Institute, The Netherlands).

SFXTs vs HMXBs: Does the difference lie in the companion wind? by Pragati Pradhan (North Bengal University, Siliguri).

Department of Physics,
Cochin University of Science and Technology, Kochi

Coordinator: V. C. Kuriakose, and Joint Coordinator: Ramesh Babu T.

Data Centre

The Data Centre is being used by M.Sc. students for doing projects, and research scholars for their Ph.D. studies. Under-graduate and post-graduate students from neighbouring colleges and institutes have carried out their summer projects/training using the facilities available at the IRC.

Areas of Research

- Physics of black holes
- Extended theories of gravity
- Bose-Einstein condensation
- General relativity and cosmology

Three research scholars are now doing their studies in these areas, and one student has been awarded Ph.D. degree.

Workshops and Meetings

IUCAA - APT Workshop on Virtual Observatory, at the Department of Physics, Sacred Heart College, Chalakudy (July 16 – 17, 2016).

Conference on Research in Astronomy: Opportunities and Challenges - III, at the Department of Physics, University of Calicut, Kozhikode (July 18 - 19, 2016).

List of Publications

C. B. Prasobh, Jishnu Suresh and V. C. Kuriakose (2016) *Thermodynamics of charged Lovelock: AdS black holes,* EPJC, 76, 207.

Pankunni Prasia and V. C. Kuriakose (2016) *Quasi-normal modes and P-V criticality for scalar perturbations in a class of dRGT massive gravity around black holes,* GReGr, 48, 89.

Pankunni Prasia and V.C. Kuriakose (2017) *Quasi-normal modes and thermodynamics of linearly charged BTZ black holes in massive gravity in (anti) de Sitter spacetime,* EPJC, 77, 27.

Lectures/Seminars/Colloquia

An era of astronomical surveys with SDSS by Vivek M. (University of Utah, Salt Lake City, USA), July 13, 2016.

Probing the dark Universe by V.C. Kuriakose (CUSAT), March 18, 2017.

The Coordinator has given the following lectures in other colleges/institutions:

Radiative processes in astrophysics (Series of lectures) at the Department of Astrophysics, Pondicherry University, October 24 - 28, 2016.

PT symmetric non-linear systems (V SERC School on Non-linear Dynamics) at the P.S.G. College of Technology, Coimbatore, December 16, 2016.

Exploring the sky at the M.E.S. College, Marampilly, March 9, 2017.

Public Outreach Programmes

Physics: Scope awareness programme for school students

This programme was organized at the Department of Physics, CUSAT for school students, during **April 04 – 08, 2016,** in collaboration with IRC, Kochi. The students were given training in assembling small telescopes. There were also lectures on basic Astronomy and Astrophysics, and topics in Physics. In addition to lectures, the students were given training on doing experiments in physics and they were given opportunity to visit different research laboratories in the department. There were 40 participants from different schools in Kerala.

Talks on basic Astronomy and demonstration to make small telescopes

This was conducted at the Federal Institute of Science and Technology (FISAT), Mukkannoor, for school students, on January 28, 2017.

Lectures, demonstration to make small telescope and sky watching

This programme was conducted for B.Sc. and M.Sc. students of the N.S.S. College, Ottapalam, on March 3, 2017.

The present research scholars, Jishnu Suresh and Lini Deavssy, and former research students, Nijo Varghese, Tharanath R. and Saneesh Sebastian have rendered valuable services in making the public outreach programmes and other IRC activities a great success.

Department of Statistics, University of Calcutta, Koklata

Coordinator: Asis Kumar Chattopadhyay, and Joint Coordinator: Narayan Banerjee

Areas of Research

- Galaxies, globular clusters, gamma-ray bursts, and star formation
- Simulation studies
- Analysis of astronomical data
- General relativity and cosmology

Projects of M.Sc. Students Supervised by Asis Kumar Chattopadhyay, Department of Statistics

- Study on the relation between earth temperature and number of sunspots on the basis of data published by NASA, by Srijani Das.

- Separation of signals from noises and mixture data on the basis of Independent Component Analysis, by Aditi Sen.

Projects of M.Sc. Students Supervised by Tanuka Chattopadhyay, Department of Applied Mathematics

- H-R diagram of globular clusters, by Suparna Sau.

- H-R diagram of stars for a real data set of stellar parameters, by Surita Paul.

- BPT diagram, by Soma Chatterjee.

- Some image analysis of astronomical objects using SAO Ds9 Software, by Prianka Ray.

Workshop and Conference

Introductory Workshop on Astrophysics and Cosmology, at the Department of Physics, Aliah University, Kolkata, during September 26 - 28, 2016.

Platinum Jubilee International Conference on Applications of Statistics, at the Department of Statistics, University of Calcutta, Kolkata, during December 21 - 23, 2016.

List of Publications

Tuli De, Rahul Bhattacharya and Asis Kumar Chattopadhyay (2016) Classification under non-Gaussian set up: An astrostatistical problem, J. App. Probab. Stat., ***11(2),*** *29.*

Krishnendra S. Ganguly, Soumita Modak, Krishna S. Ganguly and Asis Kumar Chattopadhyay (2016) *Study on temporal effects on urban malaria incidences,* Intl. J. Stat. Med. Res., **5,** 120.

Asis Kumar Chattopadhyay (2017) *Incomplete data in astrostatistics,* Wiley StatsRef: Statistics (online).

Abisa Sinha, Tanuka Chattopadhyay and Asis Kumar Chattopadhyay (2017) *Evolution of initial mass function in young massive star clusters,* Rashi, **2(1),** 18.

Soumita Modak, Asis Kumar Chattopadhyay and Tanuka Chattopadhyay (2017) Clustering of gamma-ray bursts through kernel principal component analysis, J. Comm. Stat. Sim. Comp., [http://dx.doi.org/10.1080/03610918.2017.1307393].

Visitors

Christian Robert, University of Paris, France, December 22 - 25, 2016.

Sanjeev Dhurandhar, IUCAA, Pune, December 21 - 24, 2016.

Lectures by the Coordinator

Faculty Development Programme on Pedagogy and Research, RCC Institute of Information and Technology, August 1 - 5, 2016.

UGC sponsored National Seminar on Use of Statistics in the Analysis of Socio-Economic Development: Contemporary issues in India, Departments of Economics and Statistics, Midnapore College, West Bengal, November 7 - 8, 2016.

49th ORSI Conference, Birla Institute of Management and Technology, Greater Noida, Plenary Talk, December 12 - 14, 2016.

2nd Workshop on Statistical Techniques used in Research, Department of Statistics, University of Burdwan, February 21 - 24, 2017.

School of Studies in Physics and Astrophysics, Pt. Ravishankar Shukla University, Raipur

Coordinator: Sheo K. Pandey, and Joint Coordinator: Rakesh C. Agrawal

Research Highlights

- Sheetal Kumar Sahu has been working on his PhD thesis under the supervision of S.K. Pandey, The work comprised of analysis of multi-wavelength data of a sample of radio loud elliptical galaxies observed from 2m IGO Telescope, Girawali; 2m HCT, Hanle; and archival data from SDSS (ugriz), 2MASS (JHKs), WISE, Spitzer (mid-IR), XMM, CHANDRA (X-ray), GALEX (UV), and VLA, IRAM (radio). Surface photometry was performed on the images obtained. The profiles of surface brightness, position angle, ellipticity and B4 coefficients of the galaxies were derived. Colour map, extinction map, H-alpha emission map, CO intensity map, diffuse X-ray emission map, and extinction curves of the galaxies were created in order to study the morphology, properties and physical correlations of different phases of Inter Stellar Medium, and to examine star formation processes in the galaxies. Spectra of the galaxies were analyzed. The flux of emission lines, temperature, electron density, and star formation rate for the galaxies were estimated. Based on spectral properties, the type of AGN hosting galaxies were identified.

- Amit Tamrakar is continuing his Ph.D. work under the supervision of S.K. Pandey, on the thesis entitled, "Multi-wavelength Isophotal Shape Analysis of Early Type Galaxies". By doing multiband isophotal shape analysis and ellipse fitting procedure, we are trying to find out correlations between the presence of dust and the other parameters. The work will provide clues to the roll of dust, ISM and the formation of early-type galaxies.

- Mahendra Verma has registered for his Ph.D. degree, on the thesis entitled, "Central Region of Lenticular Galaxies" under the supervision of S.K. Pandey and Sudhanshu Barwey (South African Observatory, Cape Town). The work is aimed to carry out detailed analysis of central (nuclear) regions of S0 galaxies observed with Hubble Space Telescope (HST). Volume limited sample of lenticular galaxies are selected from RC3 catalogue depending on different selection parameters. We are working on HST WFC2 archival data to see the dust and other features on central regions of galaxies. It is found that most of the galaxies are power law dominated (gamma > 0.3). We also look for 2MASS galactic data for our sample to specify the K-band magnitude. We have explored the possible correlation between Pseudo bulge and Classical bulge.

- Kalyani Bagri has been working on her Ph.D. thesis entitled, "Study of Accretion Process and Jets in X-ray Binaries" under the supervision of J.S. Yadav (TIFR, Mumbai), S.K. Pandey, and Ranjeev Misra, (IUCAA). We have analyzed the RXTE observations of GX 339-4 during its four outbursts and identify the observations when the system was in the hard state and showed a broad Iron line. We have made an attempt to fit these observations with models, which include smeared reflection to understand whether the intrinsic photon index can indeed be large. We explored the correlations between spectral parameters such as the flux, ionization level, equivalent width of the line, etc.

Ph.D. Thesis

Title: *Observational studies of type Ia supernovae.*
Student: N.K. Chakradhari
Supervisors: D.K. Sahu (IIA, Bengaluru), and S.K. Pandey.
(Pt. Ravishankar Shukla University, Raipur)

Conference

A National Conference on Signal Processing, Sustainable Energy Materials, and Astronomy and Astrophysics was organized at the School of Studies in Physics and Astrophysics, Pt. Ravishankar Shukla University, Raipur, during March 28 - 30, 2017.

Lectures/Seminars

Is there life elsewhere in the Universe?, S.M. Chitre, CEBS, Mumbai University, Kalina.

Gravitational waves, science and technology in astronomy, Ajit K. Kembhavi, IUCAA.

Looking beyond Newton's laws of motion, Naresh K. Dadhich, IUCAA.

Space astronomy and AstroSat, H.M. Antia, TIFR, Mumbai.

Plasma physics and its flourishing Universe, Mridul Bose.

Characteristics of atmospheric waves and their effect on the ambient atmosphere, Amitava Guharey.

Pushpa Khare has given special lectures to M.Sc. students and taught astronomy and astrophysics.

Avinash Khare has given special lectures to M.Sc. students and taught quantum mechanics. He also delivered a lecture on How to prepare for CSIR-NET exam?

Indranil Chattopadyay took special classes and taught cosmology to M.Sc. students.

Astronomical Activities and Public Outreach Programmes

Various astronomical activities were organized during the INSPIRE summer and winter camps. Planetarium show, sky watching programme and telescope demonstrations were organized time to time at various places.

Lectures by S. K. Pandey

Milestones in astronomy: Our place in the Universe (2nd Shri Manek M. Patel memorial lecture), at Kadi Sarva Vishwavidyalaya (SRV), Gandhinagar, Gujarat, October 19, 2016.

A fresh view of the Universe, at the seminar on Space science and technology in the service of mankind, at the Department of Physics, Hindol College, Khajurikata, Dhenkanal, Odisha, December 18, 2016.

A physicist's view of the Universe, at the Annual Convention of the Odisha Physical Society, Berhampur University, February 11, 2017.

International character of science: A shared heritage of the human race (inaugural talk), at the International Conference on Organizations Sans Boundaries, organized by Aditya Institute of Management Studies and Research, Borvili, Mumbai, February 18, 2017.

Early-type galaxies: Isophote shapes, dust and multiphase ISM, (presidential address), at the inaugural function of ASI - 2017, Jaipur, March 6 - 8, 2017.

Understanding the Universe we live in, at the Department of Culture, Government of Chhattisgarh, March 18, 2017.

Isophote shapes, dust and complex ISM in nearby ETGs (invited talk), at the National Conference, NSSEMA - 2017, School of Studies in Physics and Astrophysics, Pt. Ravishankar Shukla University, Raipur, March 28 - 30, 2017.

IRC Activities by N.K. Chakradhari

Visited the Government Primary School, Dhangaon, Chhattisgarh, and interacted with the students on August 31, 2016 and February 4, 2017.

Delivered a lecture on Ganit,Vigyanaur aur Khagolvigyan (Maths, Science and Astrophysics), at the Chhattisgarh Science Centre, Raipur on September 20, 2016.

Worked as a resource person in Science Popularization workshop for tribal students, at the Government High School, Singhiya, Chhattisgarh, delivered a lecture and organized sky watching programme, during October 15 - 16, 2016.

Given a presentation on Light curves of type Ia supernovae in Topical Course in Computational Statistics and Astrostatistics, during January 1 - 10, 2017, at IUCAA, Pune.

Delivered a lecture on Particle physics, at Bhilai Mahila College, Bhilai, Chhattisgarh on January 12, 2017.

Transit of Mercury

A sky gazing programme was held on May 9, 2016 to witness the Transit of Mercury at the IRC. The event was viewed using 8 inch Schmidt-Cassegrain Telescope available at Professor R.K. Thakur Memorial Observatory of the School. A standard solar filter was placed in front of collector plate of the telescope for safety purpose. The students and public were curious and excited to see the event. They asked several questions, which were answered by N.K. Chakradhari, L.K. Chawre and Mahendra Verma. The telescope was handled by Amit Tamrakar and Arti Choudhary. The event was broadcasted live by IBC-24-hours, Chhattisgarh TV Channel. Several people from the print-media were also available to cover the news of transit event, which was published in local daily on the next day.

स्टूडेंट्स ने देखा, सूरज के ऊपर से बिंदु की तरह गुजर गया बुध

रविशंकर यूनिवर्सिटी की भौतिकी और खगोल अध्ययनशाला में देखा गया बुध परागमन

MERCURY TRANSIT

सिटी रिपोर्टर • एक दशक में बुध सूर्य के ऊपर से 13 बार निकलता हुआ नजर आता है। 2003 और 2006 के बाद सोमवार 9 मई 2016 को यह तीसरा मौका था जब बुध सूर्य के ऊपर से होकर गुजरा। इसके बाद बुध का परागमन 2019 और 2032 में होगा। इसकी परिक्रमा की कोई समय सीमा तय नहीं है। रविशंकर विश्वविद्यालय के स्टूडेंट्स ने बेहद कौतूहल के साथ बिंदु की तरह नजर आने वाले बुध को सूर्य पर से होकर गुजरते हुए देखा। टेलिस्कोप के साथ ही दूरबीन पर सेफ्टी गार्ड के रूप में सोलर प्लेट लगाए गए थे, ताकि स्टूडेंट्स की आंखों को नुकसान न हो। 4 बजकर 40 मिनट से लेकर 6 बजकर 30 मिनट के बीच स्टूडेंट्स ने इस खगोलीय घटना को निहारा। बुध परागमन से वैज्ञानिक ज्यामिती आधार पर ग्रहों के बीच की दूरी का पता लगाते हैं। साथ ही सूर्य के आसपास पृथ्वी व दूसरे ग्रहों के घूमने के बारे में जानकारी जुटाते हैं।

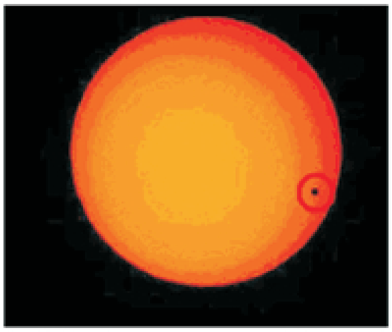
बुध छोटा है इसलिए सूर्य को ढक नहीं पाता

इस घटना कि वैज्ञानिक जानकारी देते हुए प्रोफेसर एनके चक्रधारी ने बताया कि बुध परागमन की यह घटना ग्रहण जैसी है। सूर्य ग्रहण में सूर्य और पृथ्वी के बीच में चंद्रमा होता है। चंद्र ग्रहण में सूरज और चंद्रमा के बीच में पृथ्वी होती है। वैसे ही इस खगोलीय घटना में सूरज और पृथ्वी के बीच में बुध ग्रह था। लेकिन बुध ग्रह आकार में काफी छोटा होने की वजह से चंद्रमा को ढंक नहीं पाता, यही वजह है कि ये बिंदु के रूप में सूरज के ऊपर से गुजरता नजर आया।

Source: Dainik Bhaskar 10th May 2016

बुध ने लगाया सूरज को नजर का 'टीका'

बुध पारगमन देखने लोगों ने दिखाई दिलचस्पी



कुछ ऐसा दिखता है बुध पारगमन। बुध ग्रह (लाल घेरे में)।

» टेलीस्कोप से देखी अद्‌भुत खगोलीय घटना

रायपुर (निप्र)। सोमवार की शाम बेहद खास थी। दस साल बाद ऐसी अद्‌भुत खगोलीय घटना हो रही थी, जिसका गवाह बनने हर कोई बेकरार था। रायपुरवासियों ने शाम बुध पारगमन (ट्रांजिट ऑफ मरकरी) देखा। इस मौके पर रविशंकर विवि में फिजिक्स डिपार्टमेंट की ओर से टेलीस्कोप की व्यवस्था की गई थी। विवि के लगभग 370 स्टूडेंट्स ने टेलीस्कोप से बुध को देखने का आनंद लिया। टेलीस्कोप पर ढलते नारंगी रंग के सूरज पर बुध काले तिल के रूप नजर आया। मानों वह सूरज को नजर का 'टीका' लगा रहा हो। इसके बाद यह घटना नवंबर 2019 में दिखाई देगी। सोमवार को बुध पारगमन 4:40 मिनट से सूर्यास्त तक दिखाई दिया।

क्यों होता बुध पारगमन

बुध पारगमन एक खगोलीय घटना है। सौरमंडल में सूर्य और पृथ्वी के बीच बुध और शुक्र चक्कर लगाते हैं। इनमें जब बुध या शुक्र में से कोई ग्रह पृथ्वी और सूर्य के बीच आ जाते हैं तो वह पारगमन कहलाता है। अभी बुध सूर्य और पृथ्वी के बीच आया है। इससे पहले यह नजारा 2006 में दिखाई दिया था।

सूर्य पर बुध का परागमन देखते रविवि के स्टूडेंट्स।

फोटो :नईदुनिया

"टेलीस्कोप से देखने पर सूर्य के ऊपर एक काला सा बिंदु धीरे-धीरे चलता नजर आएगा। हर पांच मिनट में इसकी स्थिति बदलती दिखेगी। किसी भी खगोलीय घटना का इंसान के जीवन पर कोई असर नहीं होता है। बस इसे देखने के वक्त एहतियात बरतनी चाहिए।

– **नंदकुमार चक्रधारी**, सहायक प्राध्यापकभौतिक संकाय रविवि

"बुध पारगमन पर सूर्य पहले सफेद सा नजर आया इसके बाद थोड़ा सा पीला दिखाई दिया फिर जब सूर्य पूरा अस्त होने के कगार पर आया तो लाल रंग का हो गया।

– **प्रियालक्ष्मी साहू**, स्टूडेंट

"दूरबीन से भी सीधे सूर्य की ओर नहीं देख सकते। इसे आंखो को नुकसान पहुंच सकता है। इससे आंखो का रेटीना जल सकता है। इसे दूरबीन पर सोलर फिल्टर लगाकर इसे देखा गया।

– **नेहा खुजूर**, स्टूडेंट

"बुध पारगमन को टेलीस्कोप से देखने पर सूरत पर एक तिल के निशान की तरह नजर आया। इस खगोलीय घटना को देखना पहला एक्पीरियंस था जिसे मैंने और सब लोगों ने खूब इन्जॉय किया।

-**मितेश साहू**, स्टूडेंट

Source: Nai Dunia 10th May 2016

List of Publications/Posters

1. *S. Joshi, P. Martinez, S. Chowdhury, N.K. Chakradhari, Y.C. Joshi, et al. (2016) The Nainital Cape Survey-IV: A search for pulsational variability in 108 chemically peculiar stars,* A&A, **590A**, 116.

2. *L.A. Balona, C.A. Engelbrecht, Y.C. Joshi, S. Joshi, ... , N.K. Chakradhari, et al. (*2016) The hot ã Doradus and Maia stars, MNRAS, **460,** 1318.

3. *Kalyani Bagri, et al.* (2016) *Systematic analysis of low/hard state RXTE spectra of GX339-4 to constrain the geometry of the system*, presented at ASI-2016, Kashmir University, Srinagar, during May 10 - 13, 2016.

4. *N.K. Chakradhari and S. Joshi* (2016) *The Nainital Cape Survey Project: A search for pulsation in CP stars,* presented at 1st BINA workshop held in ARIES, Nainital, during November 15 - 18, 2016.

5. *Kalyani Bagri, Ranjeev Misra, J.S. Yadav and S.K. Pandey (2017) Systematic spectral analysis of low/hard state of GX 339-4, during four outbursts to investigate the truncation of accretion disk, presented at ASI-2017, Jaipur, during March 6 - 10, 2017.*

6. *Sheetal Kumar Sahu, ... , N.K. Chakradhari, Mahendra Verma, Amit Tamrakar and S.K. Pandey* **(2017)** *Multiband study of a lenticular galaxy NGC1266,* presented at the National Conference on Signal Processing, Sustainable Energy Materials, and Astronomy and Astrophysics, held at the School of Studies in Physics and Astrophysics, Pt. Ravishankar Shukla University, Raipur, during March 28 - 30, 2017 (Awarded 2nd prize).

Department of Physics, North Bengal University, Siliguri

Coordinator: Bikash Chandra Paul, and Joint Coordinator: Arunava Bhadra

Areas of Research

- Cosmology
- Compact objects
- Data analysis of X-ray sources and pulsars
- Non-linear dynamics

Data Centre

Students, research scholars and faculty members of the university as well as of neighbouring colleges are using the computing facilities for their academic purpose.

Workshop

IRC has organized a two day *National Workshop on Recent Advances in Astrophysics and Cosmology,* jointly with the Department of Physics, University of North Bengal during March 17-18, 2017.

Seminars

The story of neutrinos, by Naba Kumar Mondal, SINP, Kolkata, March 9, 2017.

Exoplanets: Planets outside the solar system, by Ajit K. Kembhavi, IUCAA, March 17, 2017.

Why Einstein (Had I been born in 1844)? Relativity for everyone, by Naresh K. Dadhich, March 18, 2017.

Theoretical study of the inter-colated bilayer Graphebe, Au, Pt-Graphene and Li-Graphene structures: One kind of 2D materials and its applications, by Srimanta Pakhira, December 9, 2016.

Visitors

Sunil D. Maharaj (South Africa), Ajit K. Kembhvi (IUCAA), Naresh K. Dadhich (IUCAA), S. Mukherjee (IRC, Kolkata), Debashis Majumdar (SINP, Kolkata), Narayan Banerjee (IISER, Kolkata), Archan S.Majumdar (SNBNCBS, Kolkata), Robin Chhetri (Sikkim), Aditya S. Mondal (Visva-Bharati University, Santiniketan), Soma Mondal (Kolkata), Partha Sarathi Debnath (A.B.N. Seal College, Coochbehar), Ranjan Sharma (P.D. Women's College, Jalpaiguri), Shyam Das (P.D. Women's College, Jalpaiguri), Pragati Pradhan (St. Joseph College, Darjeeling), Pradip Chattopadhyay (Alipurduar College), Prasenjit Thakur (Alipurduar College), S. Pandey (IISER, Kolkata), Bidishsa Ghosh (Aliah University, Kolkata),

S. Biswas (IIEST, Shibpur), S. Saha (IISER, Kolkata), S. Panda (Utkal University, Bhubaneswar), S. Dutta (Burdwan University), Md. Injamul Haque (St. Xavier's College, Kolkata), H. J. Sarmah (Gauhati University, Guwahati), A. Sarkar (SNBNCBS, Kolkata), S. Ghosh (Visva-Bharati University, Santiniketan), Mosur Rahaman (Jadavpur University, Kolkata), Fazley Ahmed (Jamia Millia Islamia, New Delhi), Ng. Ishwarchandr (NIT, Agartala), H. Shanjit Singh (Rajiv Gandhi University, Itanagar), T. Khaling (Darjeeling), and Pravat Dangal (St. Xavier's College, Darjeeling).

Ph. D. Theses

Title: *Studies on very compact stars*
Student: Shibshankar Karmakar
Supervisor: S. Mukherjee
(University of North Bengal, Siliguri)

Title: *Pulse profile studies and hard X-ray properties of neutron stars*
Student: Pragati Pradhan
Supervisors: Bikash Chandra Paul, and Biswajit Paul
(University of North Bengal, Siliguri)

List of Publications

1. Bikash Chandra Paul, Pransenjit Thakur and Aroonkumar Beesham (2016) *Constraints on modified Chaplygin gas from large scale structure,* Ap&SS, **361,** 336.

2. Shubhrangshu Ghosh, Tamal Sarkar and Arunava Bhadra (2016) *Exact relativistic Newtonian representation of gravitational* static *spacetime geometries,* ApJ, **828,** 6.

3. Biplab Bijay, Prabir Banik and Arunava Bhadra (2016*) The knee in the cosmic ray energy spectrum from the simultaneous EAS charged particles and muon density spectra*, Ap&SS, **361,** 311.

4. Tamal Sarkar, Samir K. Sarkar and Arunava Bhadra (2016) *Spectral lags of flaring events in LS I+61°303 from RXTE observations* RAA, **16,** 104.

5. Tamal Sarkar, Shubhrangshu Ghosh and Arunava Bhadra (2016) *Effects of the dark energy and flat rotation curve on the gravitational time delay of particle with non-zero mass,* EPJC, **76,** 405.

6. Biplab Bijay and Arunava Bhadra (2016) *Progenitor model of cosmic ray knee,* RAA, **16,** 6.

7. Aniruddha Palit and Dhurjati Prasad Datta (2016) *Existence of limit cycles in a class of non-symmetric Lienard systems*, Ind. J. Math., **58,** 59.

8. Bikash Chandra Paul and Pransenjit Thakur (2017) *Observational constraints on EoS parameter of emergent universe,* Ap&SS, **362,** 73.

9. Bikash Chandra Paul, Pransenjit Thakur and A. Saha (2017) *Observational constraints on extended Chaplygin gas cosmologies,* Prama, **89,** 29.

10. Prabir Banik, Biplab Bijay, S.K. Sarkar and Arunava Bhadra (2017) *Probing the cosmic ray mass composition in the knee region through TeV secondary particle fluxes from solar surrounding,* PhRvD, **95,** 06314.

The Bombay Public Trust Act, 1950. Schedule VIII [Vide Rule (1)]

Name of the Trust : INTER-UNIVERSITY CENTRE FOR ASTRONOMY & ASTROPHYSICS

Address: Post Bag-4,Ganeshkhind, Pune-7. **Registration No. :F-5366 (PUNE) dated 27.1.1989.**

BALANCE SHEET AS AT 31ST MARCH 2017

Sr No.	FUNDS & LIABILITIES	Schedule No.	31.03.2017 Rs.
1	Trust Fund / Corpus	6	1,16,86,250
2	Grant-In-Aid from UGC	7	1,45,65,09,193
3	Other Earmarked Funds and Project Grants	8	24,72,47,112
4	Projects and Other Payable (Net)	9	11,65,31,960
5	Current Liabilities	10 & 10A	11,61,48,625
6	Income and Expenditure a/c	14	(22,01,95,677)
	Total		1,72,79,27,462

Sr No.	ASSETS & PROPERTIES	Schedule No.	31.03.2017 Rs.
1	Fixed Assets	11	1,10,70,96,822
2	Investments / Deposits	12	44,83,32,720
3	Project & Other Receivables (net)	13	1,27,54,787
4	Current Assets -	13	
	a) Cash, Bank balances & Revenue Stamps		7,53,57,621
	b) Loans and Advances	13A	6,83,43,734
	c) Deposits		23,32,016
	d) Prepaid Expenses		44,77,360
	e) Advance to Suppliers	13B	92,32,402
	Total		1,72,79,27,462

For Inter-University Centre for Astronomy & Astrophysics

As per Report of even date
For Kirtane & Pandit LLP
Chartered Accountants
FRN- 105215W/W100057

MSSaharabudhe
M.S.Sahasrabudhe
Admin. Officer (Accounts)

N V Abhyankar
N. V. Abhyankar
(Sr.Admn.Officer)

Parag Pansare
(Partner)
Membership No.117309

KIRTANE & PANDIT LLP FRN 105215W/W100057 Chartered Accountants

Somak Raychaudhury
Prof. Somak Raychaudhury
(Director / Trustee)

Chairperson
Governing Board

Place : Pune
Date : 14.06.2017

IUCAA, Post Bag 4, Ganeshkhind, Pune 411 007, India.
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