IUCAA

34th ANNUAL REPORT 2021-22

अंतर–विश्वविद्यालय केंद्र : खगोलविज्ञान और खगोलभौतिकी

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

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169. Aishawnnya Sharma, Department of Physics, Bahona College, Jorhat.

170. Ranjan Sharma, Department of Physics, Cooch Behar Panchanan Barma University.

171. Rathin Sharma, Department of Physics, Rabindranath Tagore University, Hojai.

172. Umesh K. Sharma, Department of Mathematics, GLA University, Mathura.

173. Amit Shukla, Discipline of Astronomy, Astrophysics and Space Engineering, IIT, Indore.

174. Alkendra Singh, Department of Physics, Institute of Science, Banaras Hindu University, Varanasi.

175. Gyan P. Singh, Department of Mathematics, Visvesvaraya National Institute of Technology, Nagpur.

176. Harinder P. Singh, Department of Physics and Astrophysics, University of Delhi.

177. Heisnam S. Singh, Department of Physics, Rajiv Gandhi University, Arunachal Pradesh.

178. Monika Sinha, Department of Physics, IIT, Jodhpur.

179. Surendra N. Somala, Department of Civil Engineering, IIT, Hyderabad.

180. Vikram Soni, Centre for Theoretical Physics, Jamia Millia Islamia, New Delhi.

181. K. Sriram, Department of Astronomy, University College of Science, Osmania University, Hyderabad.

182. L. Sriramkumar, Department of Physics, IIT – Madras, Chennai.

183. Parijat Thakur, Department of Basic Sciences and Humanities, Guru Ghasidas Central University, Bilaspur.

184. Arun V. Thampan, Department of Physics, St. Joseph's College, Bengaluru.

185. Vithal P. S. Tilvi, Department of Physics, Government College of Arts, Science and Commerce, Khandola, Goa.

186. Sunil K. Tripathy, Department of Physics, Indira Gandhi Institute of Technology, Orissa.

187. Vinutha Tummala, Department of Applied Mathematics, Andhra University, Visakhapatnam.

188. Rashmi Uniyal, Department of Physics, Government Degree College, Narendranagar, Uttarakhand.

189. Sanil Unnikrishnan, Department of Physics, St. Stephen's College, Delhi.

190. Sudhaker Upadhyay Department of Physics, KLS College, Nawada, Bihar

191. Anisul A. Usmani, Department of Physics, Aligarh Muslim University.

192. Nilkanth D. Vagshette, Department of Physics and Electronics, Maharashtra Udaygiri Mahavidyalaya, Udgir.

193. Deepak Vaid, Department of Physics, NIT, Surathkal.

194. Bhargav P. Vaidya, Discipline of Astronomy, Astrophysics and Space Engineering, IIT, Indore.

195. Murli M. Verma, Department of Physics, University of Lucknow.

196. Jaswant K. Yadav, Department of Physics, Central University of Haryana.

197. Lalthakimi Zadeng, Department of Physics, Mizoram University, Aizawl.

The Thirty-Second batch (2021) of Visiting Associates, who were selected for a tenure of three years, beginning August 1, 2021.

Sampurn Anand

Indrani Banerjee

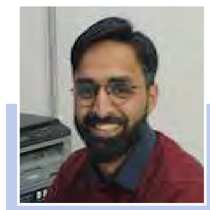
Partha Debnath

Reshma Raut Desai

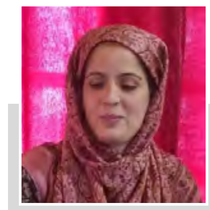
Sudip K Garain

Golam M Hossain

Bibhas Majhi



Bari Maqbool



Tabasum Masood

Biman J Medhi

Sajahan Molla

Sachin PC

Aswathy S

S Sarangi

Aishawnnya Sharma

Amit Shukla

Vithal Tilvi

Appointment of the following Visiting Associates of the Twenty-Ninth batch was extended for three years from August 2021:
Gazi A. Ahmed, Rizwan U. Ansari, Shyamal K. Banerjee, Prasad Basu, Piyali Bhar, Ritabrata Biswas, Debasish Borah, Koushik Chakraborty, Laxmikant Chaware, Mamta Dahiya, Shanti P. Devarapalli, Anoubam S. Devi, Vijayakumar H. Doddamani, Broja G. Dutta, Jibitesh Dutta, Suman Ghosh, Tuhin Ghosh, Sarbari Guha, Priya Hasan, Joe Jacob, Deepak Jain, Rajeev K. Jain, K. Jeena, Charles Jose, Jessy Jose, Minu Joy, Nishikanta Khandai, Sourav Mitra, Kamakshya P. Modak, Soumen Mondal, Hemwati Nandan, and Rajesh K. Nayak.

ORGANIZATIONAL STRUCTURE OF ACADEMIC PROGRAMMES

(As on March 31, 2022)

The Director

Somak Raychadhury

Dean,
Core Academic Programmes

Dipankar Bhattacharya

Dipankar Bhattacharya,
Head,
Computing Facilities

Gulab Dewangan,
Head,
Teaching Programmes

Aseem Paranjape,
Head,
Publications

Durgesh Tripathi,
Head,
Library

A.N. Ramaprakash,
Head,
Instrumentation

Dean,
Visitor Academic Programmes

Kandaswamy Subramanian

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

Surhud More,
Head,
Public Outreach Programmes

Ranjeev Misra,
Head,
Scientific Meetings

Somak Raychaudhury,
Head,
Infrastructural Facilities

Ranjeev Misra,
Head,
ICARDs

Kandaswamy Subramanian,
Head,
Grievance Cell

DIRECTOR'S REPORT

In over three decades, one of the main objectives of IUCAA has been to become and remain a Centre of Excellence in education, training and research among Indian Universities. Our robust and flourishing research programme is among the best in the world in Astronomy and Astrophysics (A&A) and related subjects.

IUCAA was set up to promote nucleation and growth of active groups in A&A in Indian Universities and Colleges, and to provide general guidance and help for A&A activities in India and neighbouring countries. IUCAA has always put in the best effort to achieve these objectives, and has maintained the emphasis on fundamental research and innovative teaching in almost all areas of A&A. Not only has an Astronomy Centre for Education (IUCAA-ACE) been set up at IUCAA, with a National Resource Centre of the Ministry of Education for producing online courses, over the last year a new feather has been added to this cap. The International Astronomical Union has established a centre of its Office of Education (IAU-OAE) at IUCAA, which will be part of the IUCAA-ACE activities.

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

During the last academic year, IUCAA, together with the Savitribai Phule Pune University, has started an MSc programme leading to a Physics with Astrophysics degree. In this programme, the entire second year will be taught by IUCAA faculty, along with supervision of a project for each student. In parallel, A new generation of IUCAA Centres for Astronomy Research and Development (ICARDs) have been set up all through the country, to enhance teaching and research in Indian Universities/ Colleges. Currently these are at Cooch Behar, Delhi, Manipal, Nanded, Kochi, Kolkata, Gorakhpur, Haridwar, Indore, Kozhikode, Raipur, Pilani, Silguri, Srinagar (J&K), Tezpur and Thodupaza, Workshops for academics in the region are being organised at these Centres.

A Precision and Quantum Measurement laboratory has been established in IUCAA, as a part of the DST's nationwide Quantum initiative QUEST. This facility offers to build one of the most sensitive optical atomic clocks at 467 nm wavelength, and will also aid the training of various young researchers for laser-related activities for LIGO-India.

IUCAA currently has 27 core members of faculty, including the Director, 6 Emeritus Professors, 3 Visiting and Adjunct Professors, 31 Postdoctoral fellows and 67 PhD students. There are 37 Scientific and Technical Staff and 30 members of Administrative staff. Ten students obtained their PhD during the last year.

I am very proud indeed to say that the academic members published 247 peer-reviewed papers in the previous year, with a mean impact factor of 3.34. This shows that our colleagues are not just very productive in research of the highest quality, but they are making a substantial impact on the subject at the national and international levels. Even more gratifying is the fact that the 197 Visiting Associates of IUCAA, who are faculty members at Indian Universities and Colleges, supported in their research by IUCAA, have published 411 peer-reviewed papers during the same period, with a mean impact factor of 4.32. This number has increased over the years, and clearly indicates the impact IUCAA has had in promoting and nurturing A&A research at institutions of higher education all over the country, and has provided facilities and the right atmosphere for nurturing active collaboration between members of the community of associates and the national and international communities.

The High-Performance computing facilities at IUCAA has now a capacity of 0.5 petaflops, being ranked 10th in India, and its storage has been upgraded by another 1.2 petabytes in the last six months. 42% of the time of this system is now used by non-IUCAA users in Indian Universities by remote login.

Among the various academic honours bestowed upon members of the IUCAA faculty, Kanak Saha has been awarded the Shanti Swarup Bhatnagar Award for the Physical Sciences, CSIR, for 2021, S.V. Dhurandhar has been elected Fellow, Indian National Science Academy (INSA) , and Sukanta Bose has been elected Fellow, Indian Academy of Sciences (IASc). Tarun Souradeep has been appointed Director, Raman Research Institute, Bengaluru, on deputation from IUCAA, and Dipankar Bhattacharya will join Ashoka University as the Sunanda & Santimay Basu Chair Professor in Astrophysics from April, on lien.

IUCAA has continued to be in the forefront of science popularisation and outreach activities for high school students and the general public. Regular Lecture / Demonstration Programmes for local school students have been conducted, and are very popular. During this year, coming out of pandemic restrictions, we have been able to hold both online and limited in-person events, and in the process have been reaching much larger numbers all over the country. The National Science Day was conducted over two days (27-28 February) online with virtual reality tours of our facilities plus talks and interactive events, with over 65,000 participants in the live events, and many more viewing the programmes online since then. Outreach activities included lectures / demonstrations / workshops conducted at different parts of Maharashtra and elsewhere - this included our rural outreach programmes around the LIGO-India site in the Hingoli district, and in the vicinity of IUCAA's own Girawali observatory. All these activities owe a great deal to the hard work by our talented staff (core and contractual) at IUCAA. I wish to express my sincere gratitude to every one of them.

The Pune Knowledge Cluster (PKC) was established in 2020, by the Office of The Principal Scientific Advisor, GoI under The City Knowledge and Innovation Cluster Initiative, as one of six city-based initiatives in India. The nodal administrative agency of PKC is IUCAA and its functioning is facilitated by the office of the Director, IUCAA. The PKC aims to bring together Academic Institutions, R&D organizations, Industries, Industry Associations, NGOs, Civic Bodies, Local and State government bodies to collectively work for the betterment of Pune City by optimally utilising science and technology capabilities of its partner organizations. The main projects being worked on are extensive COVID-19 related analysis and modelling, Sustainable mobility and Environmental projects including improving urban tree cover.

We deeply mourn the loss of Dr Thanu Padmanabhan (10 March 1957–17 September 2021), Padma Shri and Distinguished Professor, who was a member of the core Faculty of IUCAA, since 1992, and served as Dean of Core Academic Programmes during 1997-2014. I express our heartfelt condolences to the bereaved family and friends. He will be remembered as a central figure in the history of IUCAA.

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

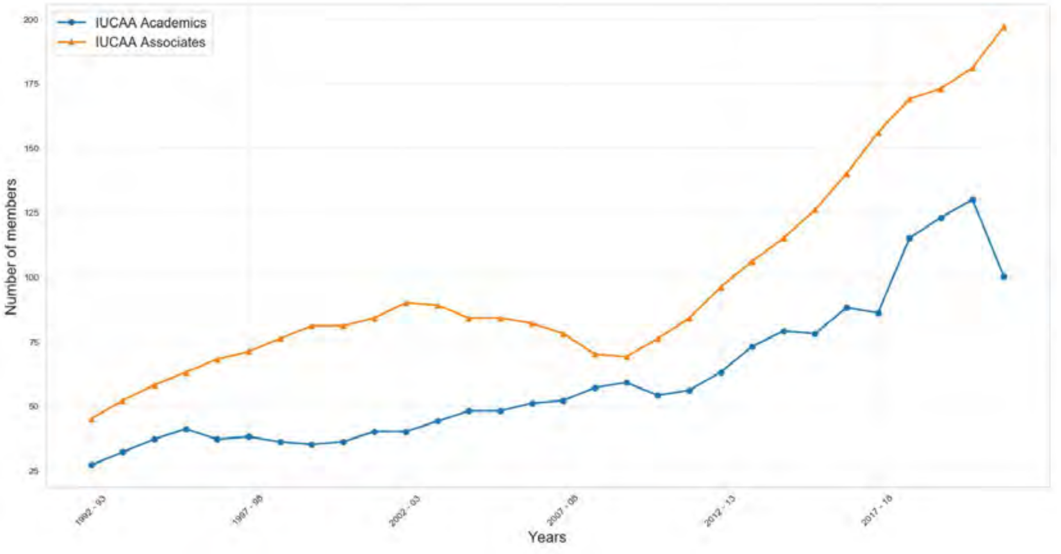
Somak Raychaudhury

Director, IUCAA

IUCAA IN NUMBERS

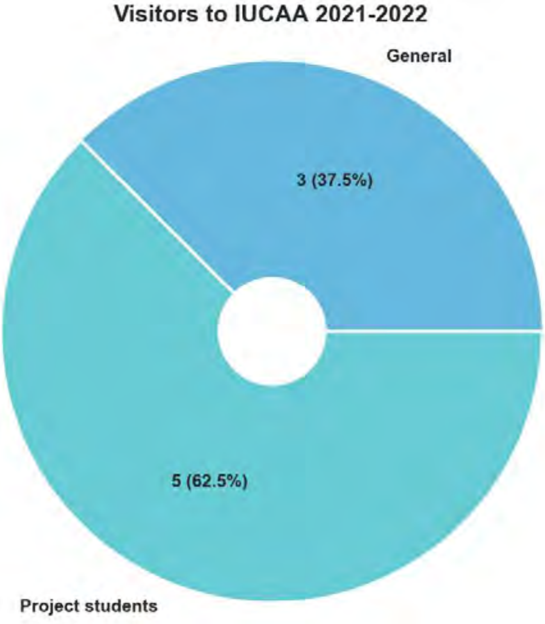
IUCAA Family across the Years

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



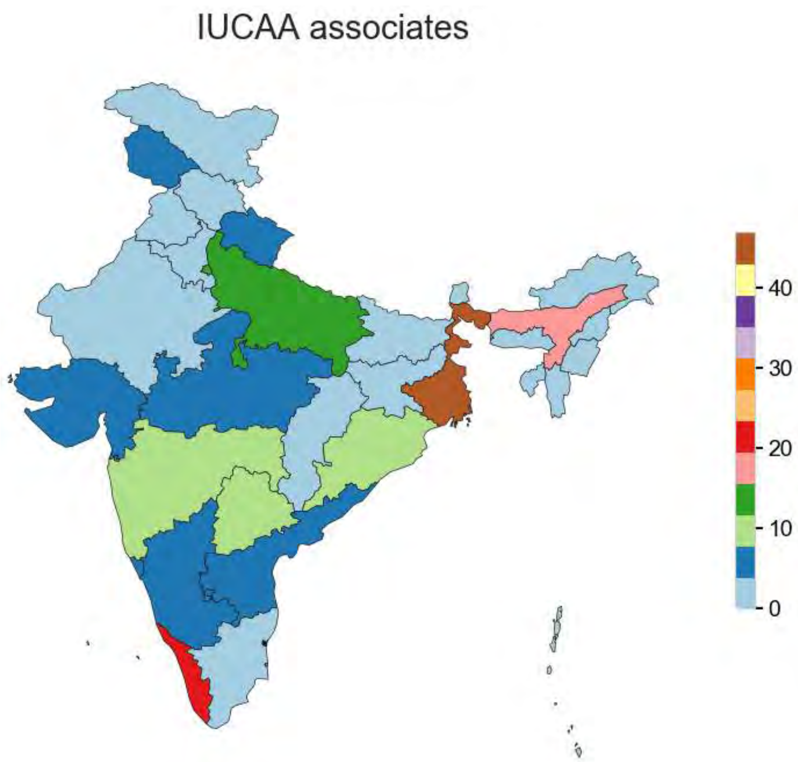
Visitors to IUCAA

Along with the Academics and the Associates, IUCAA hosts researchers from all over the globe. As the pandemic restrictions are being removed, the institute has opened its gates once again to science enthusiasts.

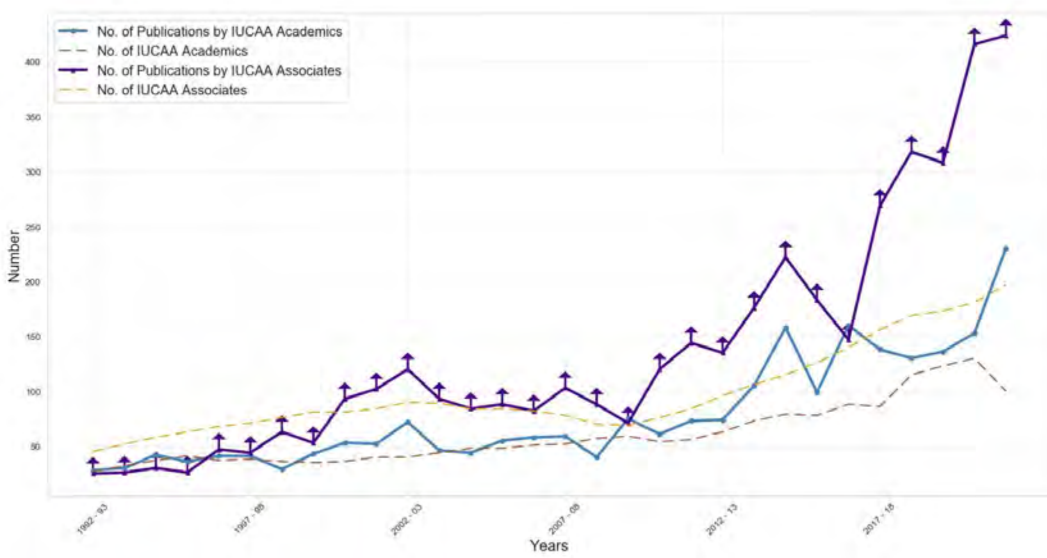


IUCAA Visiting Associates across India

IUCAA reaching out to the researchers from all over the country through its Associateship Programme. Making resources available to students all across the country.



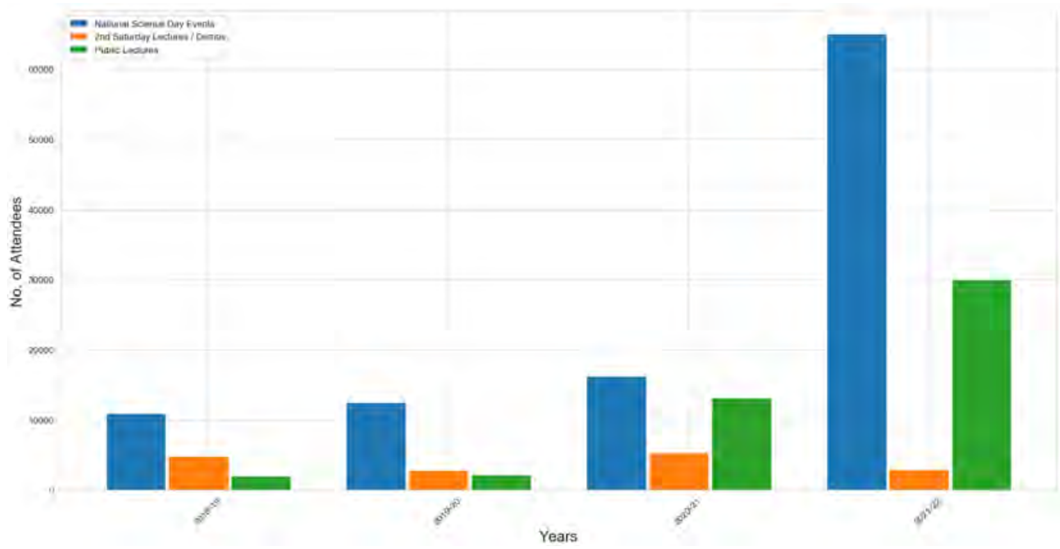
Publications across the year



The number of Publications by IUCAA visiting Associates are underestimated.

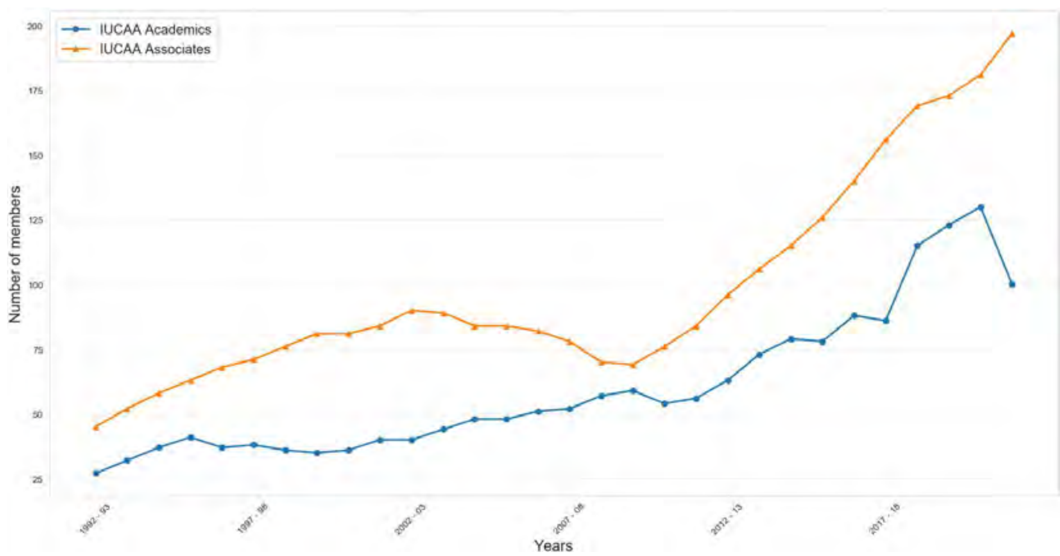
Public Outreach Events at IUCAA

The pandemic has helped IUCAA reach maximum number of people from all over the world. Making the various events accessible to everyone.



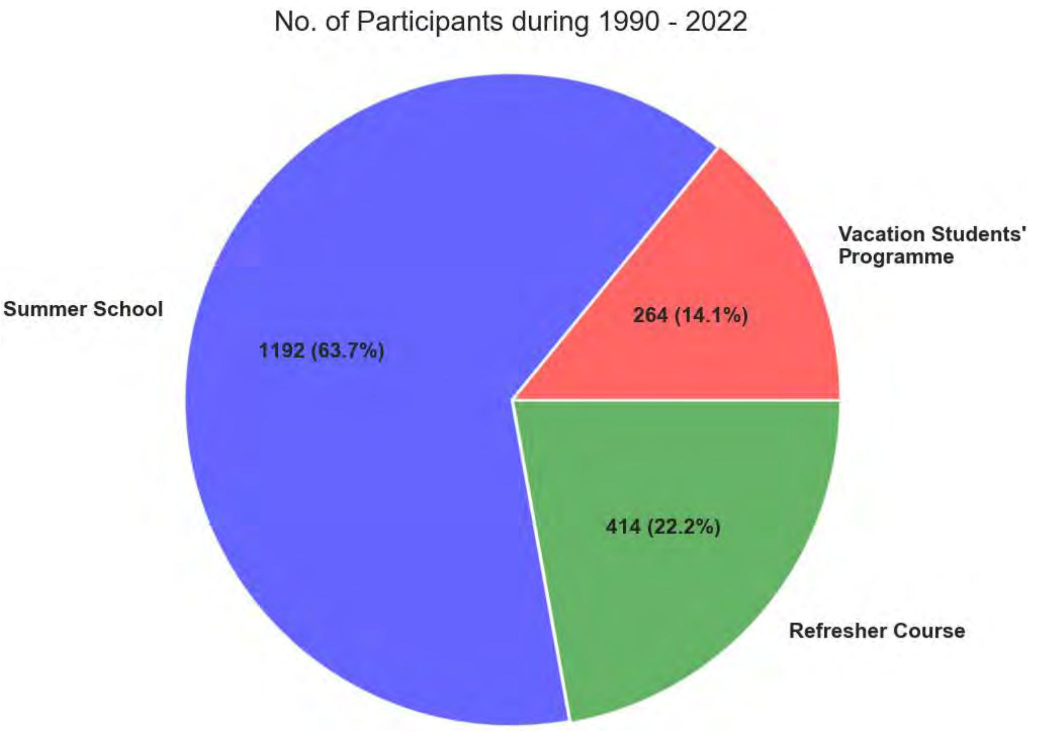
Workshops / Schools at IUCAA and Outside IUCAA

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



Summer Programmes at IUCAA

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




QUANTUM MECHANICS

RESEARCH HIGHLIGHTS FROM SALT

Southern African Large Telescope (SALT) is the largest optical telescope operating in the southern hemisphere at Sutherland, South Africa. IUCAA is one of the partner institution with ~6.5% (typically ~20 observing nights per year) share in this telescope. Astronomers from IUCAA use SALT mainly for spectroscopic studies. In the past couple of years they have carried out several systematic surveys using SALT. Here we summarise main research highlights of these surveys.

SALT survey of MIR selected powerful radio bright AGN at 0<z<3.5: IUCAA astronomers (Neeraj Gupta & R. Srianand) and their international collaborators have carried out a systematic survey of high-z radio bright quasars using SALT and the Nordic Optical Telescope. The main aim of this survey is to identify dust unbiased sample of z>1.5 radio-loud quasars that can be used as the main targets of MeerKAT Absorption Line Survey (MALS). The targets were selected based on the radio flux at L-band being more than 200 mJy and infrared colors consistent with them being at z>1.5. These selections ensured that high-z quasars were identified in a dust unbiased way.This survey has resulted in the identification of 250 new quasars (biggest sample till date for radio bright sources with a medial redshift of 1.8), 26 blazar candidates and 27 radio sources without optical counterparts. As expected, the sources in this sample are optically fainter and redder than the typical radio-selected quasars, and representative of fainter quasar population detected in optical surveys. About 20% of the sources in this sample are narrow-line AGN (NLAGN)-65% of these, at z < 0.5 are galaxies without strong nuclear emission, and 10% at z > 1.9, have emission line ratios similar to radio galaxies. The farthest NLAGN in this sample is M1513-2524 (z = 3.132), and the largest radio source (size ~330 kpc) is M0909-3133 (z = 0.884). Despite representing the radio loudest quasars (median R = 3685), the Eddington ratios measured for these quasars are similar to the Sloan Digital Sky Survey quasars having lower R. Full catalog of this quasar sample with supplementary information regarding optical and radio properties are presented in a recent paper appeared in ApJ. Systematic search for HI 21-cm and OH absorption along the lines-of-sight to these quasars is underway using MeerKAT.

SALT survey of spatially resolved Ly-α emission around radio bright quasars: Detailed investigations of the spatial distribution, kinematics, and excitation of the gas traced by the extended Ly α emission can provide vital clues on various feedback processes that drive star formation and AGN activities in high- z galaxies. IUCAA astronomers (Gitika Shukla, R. Srianand & Neeraj Gupta) and their international collaborators have used the SALT to perform long-slit spectroscopic observations of 23 newly discovered radio-loud quasars (RLQs) at 2.7 < z < 3.3 from the SALT survey. Their sample consists of powerful AGN brighter than 200 mJy at 1.4 GHz and is selected on the basis of mid-infrared colours i.e. unbiased to the presence of dust. Based on this survey they reported seven confirmed and five tentative detections of diffuse Ly ⊗ emission in the sample. They derived all the properties of diffuse Ly α emission and explored in detail its relationship to different quasar properties. They found strong dependence of Ly α halo detection rate on the extent of radio source, spectral luminosity of RLQ at 420 MHz, presence of associated C IV absorption and nuclear He II emission line equivalent width. As seen in previous surveys, the full width at half-maximum of diffuse Ly α emission in the case of confirmed detections are much higher (i.e. >1000 km/s in all, except one). Using the samples of high-z radio-loud quasars and galaxies from literature, they confirmed the correlation between the Ly α halo luminosity and its size with radio continuum luminosity. The same quantities are found to be correlating weakly with the projected linear size of the radio emission. This sample is the second largest sample of RLQs being studied for the presence of diffuse Ly ⊗ emission and fills in a redshift gap between previous such studies. The main results from this survey are presented in a recent paper published in MNRAS. This work also formed the main part of the PhD thesis of Dr. Gitika Shukla.

Time variations of Ultra Fast Outflows (UFOs): Broad Absorption Line (BAL) quasars are defined by the presence of absorption lines with large velocity widths (~few 1000 km/s) and ejection velocities (reaching upto few 10000 km/s). It is believed that these outflows could play an important role in the central black hole growth, the host galaxy evolution and the chemical enrichment of the intergalactic medium (IGM). Detailed investigation of the time variability of BAL profiles is important to obtain tight constraints on the BAL lifetime, location of the outflow etc., and provide significant insights on the origin and physical mechanisms driving the flow. For more than 5 years, IUCAA astronomers (P. Aromal and R. Srianand) have been investigating the time variability of a sample of 62 quasars from SDSS DR15 which show BALs at outflow velocities greater than 15000 km/s in their spectra using SALT. This is by far the largest sample of such objects monitored over a wide range of time scales (i.e from few months to 10 year in the quasar's rest frame). This sample has revealed emergence/disappearance of new outflow components, signatures of acceleration in some absorbing gas, correlated variability between different absorption components spread over large velocity ranges etc. Thanks to the presence of all sky photometric monitoring surveys like Zwicky Transient Factory (ZTF) it is now possible to probe the relationship between the spectral line variability and photometric light curves. Overall it appears that the amplitude of variability seen in absorption lines are much larger than what one will predict based on continuum variability from optical light curves. This either means the absorption line variabilities are either driven by line-of-sight variations in the matter distribution or the UV radiation field in these quasars have a much larger amplitude variability compared to what one sees in the optical light curves. Detailed analysis of couple of very interesting targets were published recently in MNRAS. The main survey results will form the PhD thesis work of P. Aromal.

Host galaxies of Ultra Strong Mg II absorbers (USMG II): It is well documented that Mg II absorption lines seen in the spectra of quasar probe the extended gas around normal galaxies. Ultra Strong Mg II absorbers are defined as absorbers (having rest equivalent width in excess of 3 Å, are ideal targets for studying the gas flows at low impact parameters to star-forming galaxies and/or interacting groups of galaxies. Studying such systems can provide important insights into the baryonic cycle that governs the galaxy evolution. Motivated by this, Astronomers from IUCAA (Labanya Guha & Srianand) and their collaborators have embarked on the first systematic survey of of such systems at z~0.5 with the aim to (i) identify their host galaxies and characterise the galaxy environment around these absorbers, (ii) investigate whether we preferentially select a particular galaxy population using the

ultra strong absorber selection, (iii) study the connection between the galaxy properties and that of the absorption features, and (iv) identify potential quasar–galaxy pairs where galactic outflow can be studied through down-the-barrel absorption towards the galaxy, and absorption along the quasar line of sight simultaneously. This survey has substantially increased the known host galaxies of such absorbers. The reported that at least ~33 per cent of the USMg II host galaxies (with a limiting magnitude of m_r < 23.6) are isolated and the large equivalent widths measured in these cases may originate from gas flows (infall/outflow) in single haloes of massive but not starburst galaxies. They also found galaxy interactions could be responsible for large velocity widths in at least ~17 per cent cases. The catalog of galaxies generated from this survey and main results are published recently in MNRAS. The team has just now completed a complementary survey at z~0.8 using SALT that will enable one to study the evolution of gas flows in galaxies over cosmic time. This survey will form the main body of the PhD work of Labanya Guha.

IUCAA IN NEWS

Hindustan Times Pune March 28, 2021 Pp. 8

{ EXPERT EASE } INDIA'S COOLEST RESEARCHERS

In a galaxy far, far away...

Dipanjan Sinha
letters@hindustantimes.com

Kanak Saha doesn't remember when he started counting stars as a hobby. He became fascinated by the heavens "around the age of 12", he says.

Born to an onion and potato vendor in Dinhata, in West Bengal's Cooch Behar district, he grew up with few luxuries. The clear skies of Dinhata and its small public library shaped his childhood.

"One of my teachers introduced me to the local library and a local science club where I was the only school student," says Saha, 44. "There we had an arrangement to watch the night sky with a telescope. It was one of the most fascinating experiences of my life to see the stars and planets so clearly."

In college, Saha picked physics so he could "get close to astronomy". When he signed up for a post-graduate degree at Banaras Hindu University, he was still struggling with finances. In fact, when he asked a professor if he could discuss pursuing a PhD, the latter dryly suggested Saha find a way to feed himself first.

Saha eventually got that PhD, in astrophysics, from the Indian Institute of Science in Bengaluru. He is now an associate professor at the Inter-University Centre for Astronomy and Astrophysics in Pune. And he is credited with discovering the galaxy AUDFs01, situated 9.3 billion light years away — and the first known distant galaxy emitting extreme-ultraviolet light.

This is a major development in a field where light is almost the only clue available to those trying to formulate theories about the earliest stars. "The first galaxies were formed with massive stars that were mostly hydrogen and almost no metal. These stars would explode and the theory was that they would radiate extreme ultraviolet light. Though the galaxy we found is not one of the first, we spotted extreme ultraviolet light coming from it, which reaffirms the direction we are all working in," says Saha.

As he'd expected, the discovery caused ripples when he released his findings in 2020, and has since won him an Astronomical Society of India award.

The pandemic year hit his scientific tour plans hard, though. He had to postpone his visit to Santiago, Chile, which has some of the largest ground-based telescopes in the world. Before Covid-19, he'd enjoyed travelling to observatories in cities such as Paris and Cape Town. "The trip to South Africa in 2017 was tremendous. It seems strange for an astronomer to say this but the sky was unbelievably full of stars," he says.

For children fascinated by the heavens, Saha suggests pairing passion with a good academic base. "A good foundation in physics or engineering is a must if one wants to pursue a career in astronomy," Saha says. Schools need to play a role by making the pursuit of science more enjoyable and less tedious, he adds. All it takes is a telescope.

Indian Express, Pune February 05, 2022 Pp. 5

IAU sets up centre to coordinate global efforts, mitigate impacts of growing satellites in space

ANJALI MARAR
PUNE, FEBRUARY 04

ASTRONOMY IS facing a watershed moment with the increasing number of satellites and space debris threatening the future of astronomical operations using ground-based telescopes. To address this growing menace, the International Astronomical Union (IAU) on February 3 announced the launch of the Centre for the Protection of the Dark and Quiet Sky from Satellite Interference.

The centre, to be jointly hosted by the Square Kilometre Array Observatory (SKAO) and the National Optical-Infrared Research Laboratory (NOIRLab) of the National Science Foundation (NSF), aims to work with industries and observatories to mitigate the impact of satellites on astronomical observations. The International Astronomical Union (IAU) signed a memorandum that will primarily be for optical and radio astronomy observations. The SKAO will focus on radio interference while NOIRLab will work to preserve the optical and infrared interference.

The centre, which will have contributing members from 53 institutions, will start operations from April 1. The IAU has provided the initial operational funding and the remaining support will be provided by SKAO and NOIRLab.

"Satellite constellation interference poses an existential threat to astronomical observations from the ground. The centre will facilitate global coordination of efforts of the astronomical community, in consultation with the observatories, industries, space agencies and other sectors...," said Debra Elmegreen, President, IAU during a press meet on Thursday.

Loksatta, Pune February 06, 2022 Pp. 16

ऑफिस ऑफ अ‍ॅस्ट्रोनॉमी फॉर एज्युकेशनच्या भारतातील केंद्राची आयुकामध्ये स्थापना

लोकसत्ता प्रतिनिधी

पुणे : इंटरनॅशनल अ‍ॅस्ट्रोनॉमिकल यूनियनचे (एआयू) खगोलशास्त्राच्या प्रसारासाठीचे ऑफिस ऑफ अ‍ॅस्ट्रोनॉमी फॉर एज्युकेशन (ओएई) असलेल्या सात देशांमध्ये आता भारताचा समावेश झाला आहे. पुण्यातील आंतरविद्यापीठ खगोल आणि खगोलभौतिकी केंद्र (आयुका) आणि टाटा मूलभूत विज्ञान संशोधन संस्थेचे विज्ञान शिक्षण केंद्र (एचबीसीएसई) यांच्यातर्फे भारतातील खगोलशास्त्रविषयक उपक्रम राबवले जाणार असून, याचे केंद्र आयुकामध्ये सुरू करण्यात आले आहे.

आयुकाने प्रसिद्धिपत्रकाद्वारे ही माहिती दिली. ऑफिस ऑफ अ‍ॅस्ट्रोनॉमी फॉर एज्युकेशनचे मुख्यालय जर्मनीमध्ये आहे. २०१९मध्ये त्याची स्थापना करण्यात आली होती. त्यानंतर इटली, सायप्रस आणि नेपाळमध्ये त्याचे समन्वयक केंद्र कार्यान्वित करण्यात आले. इन्स्टिट्यूट ऑफ अ‍ॅस्ट्रोनॉमिकल यूनियनने भारताबरोबरच चीन आणि इजिप्तमध्ये ऑफिस ऑफ अ‍ॅस्ट्रोनॉमी फॉर एज्युकेशन सुरू केले आहे, तर कोरियामध्ये समन्वयक केंद्र देण्यात आले आहे. भारतातील खगोलशास्त्रज्ञ, शास्त्रज्ञ आणि विज्ञान प्रचार-प्रसारातील तज्ज्ञ मिळून अभ्यासक्रमांची निर्मिती, शिक्षकांच्या प्रशिक्षणाचे कार्यक्रम आखणे, शाळांमध्ये खगोलशास्त्र शिकवण्यासाठीच्या कार्यशाळा आयोजित करणे, देशातील आणि शेजारील देशांमध्ये खगोलशास्त्र शिक्षणाची गुणवत्ता उंचावण्यासाठीचे काम भारतातील केंद्राकडून करण्यात येईल.

आयुकाचे संचालक डॉ. सोमक रायचौधुरी म्हणाले, की गेल्या काही वर्षांत खगोलशास्त्र समुदायाने मोठ्या प्रमाणात शैक्षणिक स्रोतांची निर्मिती केलेली असली, तरी त्या स्रोतांचे प्रमाणीकरण, प्रमाणीकरणाच्या निकषांची निश्चिती , शिक्षक प्रशिक्षणाची आवश्यकता आहे. त्यादृष्टीने नव्या केंद्राद्वारे माध्यमिक आणि उच्च माध्यमिक शाळांमध्ये आणि शिक्षकांसाठी खगोलशास्त्र अध्यापनासाठीच्या पद्धती, शैक्षणिक स्रोतांची प्रादेशिक भाषांतून निर्मिती करण्यात येईल. तसेच शाळांतील खगोलशास्त्राच्या शिक्षणाला उपयुक्त ठरणारे उपक्रमही आयोजित केले जातील.

केंद्राद्वारे विद्यार्थ्यांच्या मनातील खगोलशास्त्राशी संबंधित संज्ञात्मक संकल्पनांसाठी साधने विकसित करून पद्धतशीरपणे तपासण्यात येतील. तसेच खगोलशास्त्रीय संकल्पनांचे नकाशे तयार केल्याने खगोलशास्त्र शिक्षणाची चांगली समज निर्माण होऊ शकेल, असे एचबीसीएसईचे डॉ. अनिकेत सुळे यांनी सांगितले.

Indian Express, Pune February 03, 2022 Pp. 8

India among seven countries to host Office of Astronomy for Education; will be based at IUCAA

The Office will support the astronomy community and educators in bringing the subject to schools

EXPRESS NEWS SERVICE
PUNE, FEBRUARY 2

INDIA WILL be among seven countries to house an Office of Astronomy for Education (OAE) assigned by the International Astronomical Union (IAU).

According to a recent announcement, the Pune-based Inter University Centre for Astronomy and Astrophysics (IUCAA) and TIFR-Homi Bhabha Centre for Science Education (HBCSE) will together spearhead activities of this office, which became operational at IUCAA on Wednesday. The signing of the MoU in this regard was completed on February 1.

Astronomers, scientists and science outreach experts in this field in India will work towards designing curricula, develop teacher training modules, organise workshops in teaching astronomy at schools and other activities towards improving astronomy education in the country and neighbouring countries. In recent years, India has emerged as a major ... participant in inter... like the ... volved in Indian space-based missions like the Astrosat and upcoming Aditya-L1 mission to the Sun.

So far, science institutes along with a few astro clubs, either amateurs or at college level, have mainly worked for astronomy through science outreach activities, but there was no dedicated centre offering training to teachers or offering standard lessons across all Indian regional languages for all classes.

"Although the astronomy community has collectively created a large number of education resources in the last few years, there is a need for standardised ... protocols to assess the ... value of these ... are currently conducted. The activities of the centre will impact astronomy education in Indian schools and classrooms internationally," said Somak Raychaudhury, director, IUCAA.

The Indian OAE will also train teachers from neighbouring countries. The OAE centre in India will have to first understand the present teaching capabilities, beliefs and competencies of teachers before planning to restructure and introduce newer modules.

"We will need to study the manner in which astronomy is taught and how concepts are introduced to school students. Accordingly, we will need to develop ways in which the subject can be incorporated better at the ... level," said Surhud More, another IUCAA scientist.

The Indian centre will primarily develop a model curriculum that is relevant and sensitive to specific regions, cultures and languages of India or other Asian and African countries, develop teaching materials and strategies with a focus on the delivery of quality content even in low resource classrooms. This centre aims to make available astronomy resources that will help the subject gain a formal position in schools.

Along with India, IAU announced centres in China and Egypt and a nodal office in South Korea. Headquartered in Germany, the OAE was first introduced in 2019. Since then, centres or nodal offices have been functional in Italy, Cyprus and Nepal.

Pudhari, Pune February 06, 2022 Pp. 3

भारतही 'इंटरनॅशनल अ‍ॅस्ट्रोनॉमिकल'मध्ये

खगोलशास्त्राच्या उपक्रमाचे केंद्र आयुकामध्ये सुरू

पुणे : पुढारी वृत्तसेवा

इंटरनॅशनल अ‍ॅस्ट्रोनॉमिकल युनियनचे (एआयू) खगोलशास्त्राच्या प्रसारासाठीचे ऑफिस ऑफ अ‍ॅस्ट्रोनॉमी फॉर एज्युकेशन असलेल्या सात देशांमध्ये आता भारताचा समावेश झाला आहे.

पुण्यातील आंतरविद्यापीठ खगोल आणि खगोलभौतिकी केंद्र (आयुका) आणि टाटा मूलभूत विज्ञान संशोधन संस्थेचे विज्ञान शिक्षण केंद्र (एचबीसीएसई) यांच्यातर्फे भारतातील खगोलशास्त्रविषयक उपक्रम राबविले जाणार आहेत. त्याचे केंद्र आयुकामध्ये सुरू करण्यात आल्याचे प्रसिद्धिपत्रक आयुकाने जारी केले.

ऑफिस ऑफ अ‍ॅस्ट्रोनॉमी फॉर एज्युकेशनचे मुख्यालय २०१९ ला जर्मनीमध्ये सुरू झाले. त्यानंतर इटली, सायप्रस आणि नेपाळमध्ये समन्वयक केंद्र कार्यान्वित करण्यात आले. युनियनने भारताबरोबरच चीन आणि इजिप्तमध्ये ऑफिस ऑफ अ‍ॅस्ट्रोनॉमी फॉर एज्युकेशन सुरू केले, तर कोरियामध्ये समन्वयक केंद्र देण्यात आले आहे. भारतातील खगोलशास्त्रज्ञ, शास्त्रज्ञ आणि विज्ञान प्रचार-प्रसारातील तज्ज्ञ मिळून अभ्यासक्रमांची निर्मिती, शिक्षकांच्या प्रशिक्षणाचे कार्यक्रम आखणे, शाळांमध्ये खगोलशास्त्र शिकवण्यासाठीच्या कार्यशाळा आयोजित करणे, देशातील आणि शेजारील देशांमध्ये खगोलशास्त्र शिक्षणाची गुणवत्ता उंचाविण्यासाठीचे काम भारतातील केंद्राकडून करण्यात येईल.

'विद्यार्थ्यांच्या मनातील खगोलशास्त्राशी संबंधित संज्ञात्मक संकल्पनांसाठी साधने विकसित करून पद्धतशीरपणे तपासण्यात येतील. तसेच, खगोलशास्त्रीय संकल्पनांचे नकाशे तयार केल्याने खगोलशास्त्र शिक्षणाची चांगली समज निर्माण होऊ शकेल,' असे एचबीसीएसईचे डॉ. अनिकेत सुळे यांनी सांगितले.

> गेल्या काही वर्षांत खगोलशास्त्र समुदायाने मोठ्या प्रमाणात शैक्षणिक स्रोतांची निर्मिती केलेली असली, तरी त्या स्रोतांचे प्रमाणीकरण, प्रमाणीकरणाच्या निकषांची निश्चिती, शिक्षक प्रशिक्षणाची आवश्यकता आहे. त्यादृष्टीने नव्या केंद्राद्वारे माध्यमिक आणि उच्च माध्यमिक शाळांमध्ये आणि शिक्षकांसाठी खगोलशास्त्र अध्यापनासाठीच्या पद्धती, शैक्षणिक स्रोतांची प्रादेशिक भाषांतून निर्मिती करण्यात येईल.
>
> - डॉ. सोमक रायचौधरी, संचालक, 'आयुका'

ASTRONOMICAL SOCIETY OF INDIA@50

Indian Express Pune, 29 March 2022, Pp. 5

Scientists underscore need to skill youth for next generation astronomy

ANJALI MARAR
ROORKEE, MARCH 28

FROM 100 astronomers in the early 1970s, the Astronomical Society of India (ASI) today has grown to become an institute having 700 members.

In its journey spanning five decades, the society has witnessed a slow but steady growth with India now being part of at least three mega science projects – the Square Kilometre Array (SKA), the Thirty Metre Telescope (TMT), and the Laser Interferometer Gravitational-Wave Observatory (LIGO) – among other collaborations. And as these facilities become ready in about a decade from now, the ASI officials feel that there would be a need of 500 active astronomers and are hopeful of taking the ASI membership to 2,000.

The slow growth was largely due to the fact that astronomical studies and research remained confined to a select few institutes like the Aryabhatta Research Institute of Observational Sciences (ARIES) in Nainital, the Indian Institute of Astrophysics (IIA), Bengaluru or the TIFR – National Centre for Radio Astrophysics ... Pune, predominantly because they owned and operated telescopes.

"In the earlier days, most researchers were pursuing cosmology whereas the number of students studying observational astronomy was low. Even when the Indian Institute of Science, Bengaluru started the joint astronomy programme, there were just five students during the initial batches," Dr GC Anupama, the incumbent ASI president, told The Indi... Express.

Among the planned year-long celebrations marking the ASI's golden jubilee will be the revival of the society's Young Astronomers Meet

... from outside the ... a trend ...

... ing number of students was the spread of astronomy courses outside the national institutes into the IITs, IISERs and so on. But we still have to make a significant presence in the universities and colleges, where the research component has to be increased," said Anupama. Professor A...

... high quality human resources. What we now need is inspiring faculty to lead the next generation of astronomers," said Kembhavi, who suggested that future ASI meetings ... more interest ...

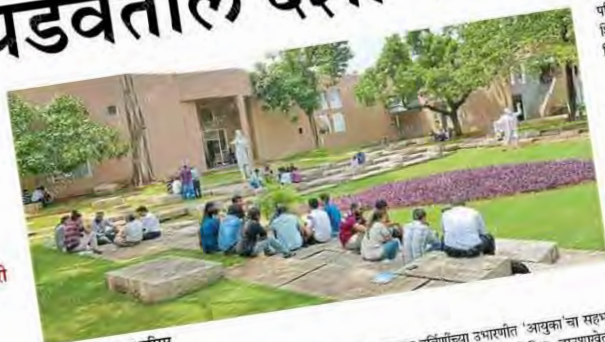
... strongly feel that it is time India encashed on its strengths in instrumentation, IT and engineering, whose contribution in ...ng, maintaining and up... telescopes and observ... facilities will only grow ...ming years. ...n we start obtaining the 10 metre or the ...class telescopes, as... will have to function and work closely ...entists, engineers ... specialists," said ... urged the ASI to ...ch industry and ... funds under their corporate social responsibility (CSR) scheme.

Among the planned year-long celebrations marking the ASI's golden jubilee, Dipankar Banerjee, while speaking at the 40th ASI meet underway at IIT-Roorkee on Monday, said the society will soon revive its Young Astronomers Meet (YAM).

"We plan to have more interactions with the International Astronomical Union, other Indian global societies working in the field of astronomy alongside engaging those working in the planetaria," said Banerjee, director, ARIES, Nainital.

संशोधक घडवतील देशाचे भविष्य

आंतरविद्यापीठीय खगोलशास्त्र आणि खगोलभौतिकी केंद्राचा (आयुका) स्थापना दिन आज (ता. २९) आहे. संशोधनासह विज्ञान प्रसारात महत्त्वपूर्ण भूमिका बजाविणाऱ्या या संस्थेचे संचालक **डॉ. सोमक रायचौधरी** यांच्याशी यानिमित्ताने केलेली बातचीत...



'आयुका'चा रम्य परिसर.

सम्राट कदम

प्रश्न : कोरोनामुळे प्रथमच 'आयुका'चा स्थापना दिन विद्यार्थ्यांविना होत आहे. लॉकडाउनमध्ये 'आयुका'चे कार्य कसे सुरू ...

डॉ. सोमक रायचौधरी ... हा प्रामुख्याने संस्थेबाहेरचे ... असतो. दरवर्षी आम्ही यानि... कार्यक्रम, प्रदर्शन भरव... 'आयुका'च्या स्थापनेपास... आयोजित केली आहे. ... सर्व कार्यक्रम ऑनला... जगभरात गेलो. जून... लोकांपर्यंत पोहोचले... कोणताही कार्यक्रम ... सहभाग नोंदवला. ... अमर्याद करणारी हे... शिक्षक प्रशिक्षण ... पोहोचतोय.

: शास्त्र... तुम्ही लॉकड...

: लॉकड... ठरला. कार... इटली, प्रयास बंद...

... संशोधनाकडे जास्त लक्ष दिले. परंतु, माझे काम जर प्रयोगशाळेत असते तर हे शक्य नव्हते. कारण लॉकडाउनचा जास्त परिणाम प्रयोगांवर झाला. खगोलशास्त्रातील निरीक्षणे ...थे थांबले; परंतु, प्रचंड प्रमाणावरील सैद्धांतिक माहितीवर ... संशोधन मला करता आले. परंतु, ... काळ होता.

अशा महाकाय दुर्बिणींच्या उभारणीत 'आयुका'चा सहभाग असेल. अशा महाप्रकल्पांसाठी विविध ज्ञानशाखेतील कौशल्यप्राप्त युवकांची गरज असते. देशातील राष्ट्रीय संशोधन संस्थांकडे पुरेशा संख्येने असे लोक नाहीत. त्यामुळे संशोधन संस्थांनाही विद्यापीठांबरोबर संबंध प्रस्थापित करावा लागेल. आयुका हे आंतरविद्यापीठीय केंद्र असल्यामुळे देशभरातील विद्यापीठांना खगोलशास्त्राशी निगडित सहकार्य आणि ... प्रयत्न करणार आहोत. देशातील नामवंत ... आमचे संबंध मागील काही ... निगडित ...

परिप्रेक्ष्याला विविधांगी बनवेल. ज्यामुळे आंतरविद्याशाखीय शिक्षण शक्य होईल. पर्यायाने संशोधनाला आणि व्यक्तिमत्त्व विकासाला चालना मिळेल.

: आंतरराष्ट्रीय स्तरावील भारताच्या वैज्ञानिक वाटचालीकडे कसे पाहता?

: स्वातंत्र्यापासून संशोधनामध्ये आपले योगदान मर्यादितच राहिले. फक्त राष्ट्रीय संशोधन संस्थाच संशोधन करतात. त्यांचे आजवरचे कार्यही महत्त्वाचेच आहे. परंतु, त्यांच्याकडे उपलब्ध संसाधने, संशोधकांची संख्या आणि संशोधनाच्या वाढत्या गरजा याबाबत त्यांना मर्यादा आहेत. असे असले तरी भारतीय शास्त्रज्ञ आंतरराष्ट्रीय सहकार्याने संशोधन करतात, तेही विशिष्ट प्रकल्पापुरतेच. 'सर्न'सारखी प्रयोगशाळा, जिथे 'हिग्स बोसान'चा शोध लागला, त्यात अगदी मागच्या वर्षी देश म्हणून आपण सहभागी होतो. एकविसावे शतक बदलांचे आहे. संशोधनासाठी आंतरराष्ट्रीय सहकार्य अनिवार्य आहे. आपणही थर्टी मीटर टेलिस्कोप, लायगो, एसकेए यांसारख्या प्रकल्पांत सहभागी आहोत. आंतरराष्ट्रीय संशोधनासाठी भारतातच आवश्यक साहित्य, सॉफ्टवेअर, अभियांत्रिकी रचना विकसित करत आहोत. भारतातील संशोधकांसह उद्योगांनाही त्याचा फायदा होत आहे. विज्ञान नुसतं आंतरराष्ट्रीय सहकार्यासाठी नाही, तर द्विपक्षीय संबंधांसाठीही उपयुक्त आहे.

: देशाच्या वैज्ञानिक प्रगतीतील अडथळे कोणते?

: आपण हे मान्य करायला हवे, की संशोधनकर्त्यां... ...कडे प्रगत देशांच्या तुलनेत खूपच ... फक्त ०.६ टक्के ...

Indian Express, Pune May 25, 2021 Pp. 9

BRICS astronomers seek more collaboration, plan to establish regional data centre

ANJALI MARAR
PUNE, MAY 24

INDIA COULD play a lead role in setting up a data centre network which will process and archive large volumes of astronomical data generated by the future network of observatories that will be built and operated by BRICS nations.

A proposal in this regard was among other key deliberations made by scientists and government representatives of Brazil, Russia, India, China and South Africa during the 7th BRICS Astronomy Working Group (BAWG) virtual meet held from May 19 to 20.

This year's meeting, under the Science, Technology and Innovation track of BRICS 2021, was hosted by India, which took over the presidency in January 2021.

The meeting stressed on increasing collaborations between the member countries, and sharing, networking and optimising the use of all currently operational telescopes located across BRICS nations. The BRICS Astronomy team has plans to initiate flagship projects, which will be mega collaborations requiring large funding from the member countries. One of the proposals is also to establish a network of telescopes across BRICS nations.

In the international meet held last week, BAWG has identified the creation of a Regional Data Network through one such flagship programme.

"Once there is a network of telescopes that will simultaneously track major celestial events, there will be huge amounts of data generated. All this data will need to be transported, processed and archived which can be achieved through a Data Network," said Yogesh Wadadekar, senior scientist at TIFR-National Centre for Radio Astrophysics (NCRA) and Principal Investigator of the proposal titled 'BRICS Intelligent Telescope and Data Network'.

With India being part of building mega projects like the Square Kilometre Array (SKA), the scientific community is well aware of the need for possessing large data centres in the coming future.

He further said, "Under this joint proposal put forth by India, we plan to provide the necessary infrastructure required to handle such large volumes of data."

Though the final funding modalities for the project is still under consideration and being worked out by the Department of Science and Technology (DST) in India, it has been agreed that every country will contribute one million Euros, annually. The South African researchers have been awarded some initial seed funding by their government whereas the project proposals submitted to the governments of China, Brazil and Russia are in their advanced stages of approval.

Prof Ranjan Gupta, from the Inter University Centre for Astronomy and Astrophysics (IUCAA) and chairman of BAWG, said, "The annual funds will mainly be spent on building small equipment, and providing fellowships to doctoral and post-doctoral students."

He said the DST could float 'Call for Proposals' under the BRICS Astronomy collaboration towards the end of 2021. "Funding matters will be taken up once the proposals from BRICS nations are accepted," said Prof Gupta.

The BAWG envisages a Human Capacity Building programme, wherein professionals will be skilled to be employed once the network of telescopes and data centre are up and running in future.

"We will engage with college, university, doctoral students and through training schools and workshops, offer training and skilling," said Wadadekar.

Maharashtra Times Pune March 01, 2022 Pp. 4

दीर्घिकांच्या अभ्यासात नागरिकांचा सहभाग

'पीकेसी'च्या 'एक दशलक्ष दीर्घिका' प्रकल्पाचे उदघाटन

म. टा. प्रतिनिधी, पुणे

... लक्षावधी दीर्घिकांच्या ...

यांच्या उपस्थितीत या प्रकल्पाचे ऑनलाइन पद्धतीने उद्घाटन झाले. याप्रसंगी ज्येष्ठ खगोलशास्त्रज्ञ आणि 'पीकेसी'चे समन्वयक प्रा. अजित केंभावी, 'एक दशलक्ष दीर्घिका' प्रकल्पाचे समन्वयक प्रा. सुधांशू बर्वे उपस्थित होते.

एका दीर्घिकेत शेकडो अब्ज तारे आणि विश्वात अब्जावधी दीर्घिका असल्याचे खगोलशास्त्र सांगते. सध्याच्या काळात अत्याधुनिक टेलिस्कोप आणि सीसीडी कॅमेऱ्याच्या साह्याने कोट्यवधी दीर्घिकांची छायाचित्रे काढणे खगोलशास्त्रज्ञांना शक्य झाले आहे. या कोट्यवधी दीर्घिकांचे त्यांच्या दृश्य गुणधर्मांनुसार (आकार, आकारमान, वस्तुमानाचे वितरण आदी) वर्गीकरण करता आल्यास विश्वातील या महाकाय रचनांचे नेमके स्वरूप समजणे खगोलशास्त्रज्ञांना शक्य होऊ शकते. मात्र, दीर्घिकांच्या छायाचित्रांच्या प्रचंड डेटाचे परिपूर्ण विश्लेषण करणे हे संख्येने मर्यादित असलेल्या खगोलशास्त्रज्ञांना शक्य नाही. अशा स्थितीत भारतच नाही; तर जगभरातील विद्यार्थी आणि नागरिक हे खगोलशास्त्रज्ञांना घरबसल्या, फावल्या वेळेत दीर्घिकांचे वर्गीकरण करण्यासाठी मदत करू शकतात.

या प्रकल्पाबाबत प्रा. बर्वे म्हणाले, 'एक दशलक्ष दीर्घिका या ऑनलाइन सिटीझन सायन्स उपक्रमात नागरिकांना दीर्घिकांच्या छायाचित्रांचे संच 'पीकेसी'च्या वेबसाइटवर उपलब्ध करून देण्यात आले आहेत. प्रत्येक छायाचित्र तपासताना नागरिकांना त्यासोबत विचारण्यात आलेल्या प्रश्नांची उत्तरे द्यावी लागतील. ही उत्तरे दिल्यावर दीर्घिकेचे सर्वसाधारण वर्गीकरण होईल. या प्रक्रियेत काही वेळा एखाद्या दीर्घिकेच्या नव्या गुणधर्माचा शोध लागणेही नाकारता येत नाही. प्रत्येक छायाचित्राचे विश्लेषण शेकडो नागरिकांनी केल्यानंतर त्या दीर्घिकेविषयी मिळणारी बहुमान्य माहिती आर्टिफिशिअल इंटेलिजन्स (एआय) विकसित करण्यासाठी उपयुक्त ठरेल. 'एआय'चा उपयोग करून अब्जावधी दीर्घिकांचे वर्गीकरण भविष्यात शक्य होईल.'

प्रा केंभावी म्हणाले, 'पीकेसी'मधून संशोधन आणि शिक्षण संस्था, उद्योग यांच्यासोबत विविध प्रकल्पांमध्ये नागरिकांनाही प्रत्यक्ष सहभागी केले जात आहे. वैज्ञानिक माहितीच्या प्रचंड साठ्याचे विश्लेषण करण्यात, माहिती जमा करण्यात, संगणकीय प्रक्रियांमध्ये विद्यार्थी आणि नागरिक आम्हाला मदत करू शकतात. येत्या काळात खगोलशास्त्रा प्रमाणेच जीवशास्त्रामधील सिटीझन सायन्स प्रकल्प राबवले जातील.' 'एक दशलक्ष दीर्घिका' या प्रकल्पात सहभागी होण्यासाठी विद्यार्थी आणि नागरिकांनी http://csa.pkc.org.in/ या संकेतस्थळाला भेट द्यावी.

Indian Express, Pune 29.01.2022 Pp. 3

SPPU to set up mathematics lab

Pune: After successfully establishing a science park for students on campus to create awareness about science and generate curiosity among them for the subject, the Savitribai Phule Pune University is now going to set up a maths museum to genera[te] interest in mathematics. A committee has ... ted to come up with plans for est... members of SPP... from Bharat Fo... committed to s...

Dr Nitin Ka... said, "The id... from the Cen... versity is su... have been ... successful... fortunate ... ists, Bab... Bharat F... ting it u... He has ev... travel and study ... India or abroad."

WWW.INDIANEXPRESS.COM

THE INDIAN EXPRESS, THURSDAY, DECEMBER 30, 2021 Pp. 5

Next 25 years exciting time for science in India: CSIR chief

EXPRESS NEWS SERVICE
PUNE, DECEMBER 29

THE COUNTRY will see a number of fundamental discoveries made here in the upcoming 20 to 25 years, said Dr Shekhar Mande, director general of the Council of Scientific and Industrial Research (CSIR), on Tuesday.

Mande was speaking on 'India's S&T journey in the post Independence era' organised to mark the 33rd foundation day of the Inter University Centre for Astronomy and Astrophysics (IUCAA). This was also the first of the lecture series organised by the Pune-based university to mark 75 years of India's independence.

"We are at a particular stage that in the coming 20 to 25 years, we are going to see a very exciting period for our country. There will be many fundamental discoveries and the future of science actually lies very firmly in the Indian soil," said Mande.

He said India's progress and scientific achievements, during the past 75 years, have been far ahead compared to the 50-60 contemporary countries that won independence around the 1940s and 1950s, "including our neighbours".

The Covid-19 pandemic and India's response, its strategies to tackle the outbreak and being the

Shekhar Mande

first to identify the disease to be an air-borne one, even prior to the declaration made by the World Health Organisation, all showcase the critical situations which Indian scientists are capable of handling today, he said.

"The pandemic saw many collaborative works in the field of biology, like never before," said Mande.

With the fresh SARS Cov-2 variant, Omicron, looming and Covid-19 cases once again beginning to see a spike in many parts of the country and world over, the CSIR chief urged people to fix concealed ultra-violet set-ups installed in their ACs to control the spread of the infection indoors. He shared that the infection spread was found to be reduced by 60 to 70 per cent with this intervention, which has been made in the Parliament and the AC coaches of trains operated by the Indian Railways.

"An effective way to inactivate the virus in closed rooms supported by ACs would be by using UV-light. I urge all universities and institutions to get this setup fixed in their offices, auditoriums,etc. The only care that needs to be taken is that UV light is not exposed to humans," suggested Mande.

India became only the second country to use indigenously developed bio-fuel to operate its defence aircraft, Mande said

On the future challenges before the scientific community, Mande said that scientists at a number of CSIR labs were working on developing some advanced technologies to address the effective use of hydrogen, finding alternatives to fossil fuels and ways to perform carbon capture-storage-use.

Sharing the latest developments from the CSIR labs, Mande said that recently, India became only the second country in the world to use indigenously developed bio-fuel to operate its defence aircraft. By August next year, the demonstration of unmanned aerial vehicles — commonly used in disaster management, remote sensing, surveillance and telecommunications — operable at a height of about 20 km above the earth's surface will be undertaken.

Indian Express, Pune February 09, 2022

PKC'S CITIZEN SCIENCE ASTRONOMY PROGRAMME

'One Million Galaxies' to make astronomy accessible

ANURADHA MASCARENHAS
PUNE, FEBRUARY 8

AT PUNE Knowledge Cluster (PKC), the mission is to bring exciting science avenues to the doorstep of citizens and make the astronomy for all mission successful. Towards that goal, 'One Million Galaxies' — a citizen science astronomy programme, will be launched on the upcoming Science Day (February 28) with an aim to involve citizens to get over the difficulty of examining the vast amounts of data collected by astronomers.

PKC's principal investigator Prof Ajit Kembhavi told The *Indian Express*, "The programme enables interested people, who may not have any training in astronomy, to help find features in galaxies. All that they will need is access to a basic computer, laptop, tablet or smartphone and a reasonable internet connection, of the kind available through a cell phone data package. The required training will be provided through short training sessions over a video link. Trained persons can examine galaxies for features at their convenience from the comfort of their home and should be able to cover a few hundred galaxies in a few hours which can be spread over a week or two."

PKC hopes to produce an atlas of a million galaxies in some months. *Express*

With committed participants, PKC hopes to produce an atlas of a million galaxies in some months. "This data will be made publicly available for use by astronomers and others all over the world and will be an important contribution by India, made possible by its citizens," Dr Disha Sawant of PKC who manages the programme said.

PKC has been established by the Office of the Principal Scientific Adviser to the Government of India. It aims to bring together academia, research and development institutions and the industry of Pune to address the challenging problems of the region through innovative means, using scientific knowledge.

PKC is committed to encourage and empower common citizens by inviting their participation in scientific programmes. It also enables citizens to participate directly in scientific p... helping to create da... ple, which will be u... sional scientific in...

The interacti... form for citizen... omy projects... Million Galaxi... one, was lau... programme... tested with... astronom... homema... and others.

Encouraged by the excellent results obtained, 'One million Galaxies' has been launched for any interested person located anywhere in India. It is expected that there will be participation ...me other countries too. ...e has been in... ...mmes

Sakal Pune Today, February 28, 2022 Pp. 1

असा साजरा करा विज्ञान दिन

व्हर्च्युअल कार्यक्रमांचे आयोजन; व्याख्यानांची मेजवानी

पुणे, ता. २७ : राष्ट्रीय विज्ञान दिनाच्या पार्श्वभूमीवर शहरात विविध कार्यक्रमांचे आयोजन करण्यात आले आहे. मात्र कोरोनाचे निर्बंध पाहता बहुतेक प्रदर्शने, व्याख्याने आणि कार्यक्रम व्हर्च्युअल आयोजित केले आहे.

राष्ट्रीय रेडिओ खगोलभौतिकी केंद्र

ऑनलाइन विज्ञान प्रदर्शनाचे आणि व्याख्यानांचे आयोजन केले आहे. सोमवार (ता. २८) आणि मंगळवार (ता. १) आयोजित होणाऱ्या या प्रदर्शनाचे उद्घाटन ज्येष्ठ शास्त्रज्ञ डॉ. सुरेंद्र कुलकर्णी यांच्या हस्ते होणार आहे. प्रदर्शनात पोस्टर आणि व्हिडिओही प्रदर्शित करण्यात येणार आहे. जायंट मीटरवेव्ह रेडिओ टेलिस्कोपची व्हर्च्युअल सफर प्रेक्षकांना करता येणार आहे. देशभरातील ३०० हून अधिक शाळांतील ५५८ विज्ञान प्रकल्प या व्हर्च्युअल प्रदर्शनात मांडणार आहे. एनसीआरएच्या युट्यूब ... आणि फेसबुकवरही ...

पुणे नॉलेज क्लस्टर

अवकाश संशोधन नागरिकांचा सहभाग वाढविण्यासाठी 'एक दशलक्ष आकाशगंगा' या उपक्रमाची सुरुवात करण्यात येणार आहे. ज्येष्ठ शास्त्रज्ञ डॉ. अजित कैंभावी हे लोकार्पण करणार आहे. **सहभागासाठी स्कॅन करा.**

आंतरविद्यापीठीय खगोलशास्त्र आणि खगोलभौतिकी केंद्र (आयुका)

...यावतीने रविवारी विज्ञान दिनाचे व्हर्च्युअल ...ण्यात आले होते. डॉ. जयंती नारळीकर ...ष मान्यवरांची व्याख्याने ...यमातून प्रसारित करण्यात ...या युट्युब चॅनलवर हे सर्व

डिजिटल पोर्टल

...तंत्रज्ञानातील माहितीचा खजिना घेऊन ...मवारी (ता. २८) लोकार्पण करण्यात ...तील माहिती, लेख, व्याख्याने आणि ...लेल्या या पोर्टलचा सर्वसामान्यांना ... आहे.

Indian Express, Pune February 28, 2022 Pp. 5

'Growing number of satellites are threat to ground-based telescopes

EXPRESS NEWS SERVICE
PUNE, FEBRUARY 27

THE RISING number of satellites in space during recent years is threatening data obtained by ground-based telescopes, said Somak Raychaudhury, Director of Inter-University Centre for Astronomy and Astrophysics (IUCAA) during the National Science Day celebrations organised on Sunday. He was responding to a question from the 'Ask a Scientist' segment on future telescopes.

"The ground-based telescopes will not be obsolete. But the growing number of satellites in the name of space tourism is space vandalism and could affect (data obtained) ground-based telescopes," said Raychaudhury.

He said that space-based telescopes like the Hubble Space Telescope (HST) or the recently launched James Webb Space Telescope (JWST) will not be able to do the tasks that a ground-based telescope does. HST observes in the ultraviolet bandwidth whereas JWST can look in the near-infrared spectrum. "But there will be a need for more ground-based telescopes," he added.

The National Science Day celebrations was held virtually this time and eminent cosmologist Professor Jayant Narlikar answered various questions from the participants. On the chances of computers replacing humans in doing science, Narlikar said, "The use of computers will be a necessity and they will be used more often to perform non-analytical and large calculations."

To this, mathematician Mangala Narlikar responded, "Computers perform as per human instructions and cannot replace human ability to think."

During the day-long virtual celebrations, there were popular talks on space weather, JWST, India's maiden mission to the Sun called the Aditya L1 mission along with the special virtual tour of the IUCAA campus and its observatory in Girawali.

IUCAA scientist among 2021 Shanti Swarup Bhatnagar winners

EXPRESS NEWS SERVICE
PUNE, SEPTEMBER 26


Kanak Saha

CITY-BASED astrophysicist Kanak Saha was among the 11 recipients of the 2021 Shanti Swarup Bhatnagar (SSB) prize, given by the Council of Scientific and Industrial Research (CSIR) on Sunday.

Every year, CSIR presents this award to scientists below 45 years of age for their contributions in biology, chemistry, mathematics, physics, medicine, engineering and earth, atmosphere, ocean and planetary sciences. The award comprises a cash prize of Rs 5 lakh.

The 2021 SSB winner list did not feature any woman scientist.

Vice-President M Venkaiah Naidu presided over the CSIR's 80th foundation day celebrations in New Delhi on Sunday. Naidu urged CSIR to turn futuristic and and focus on agriculture research. He also listed climate change, pollution, epidemic and pandemic outbreaks among the growing challenges that the scientific community will have to focus on.

Saha currently works at the Inter-University Centre for Astronomy and Astrophysics (IUCAA) in Pune and leads st...

ies on galaxies, their formation and evolution. Specialising in ultraviolet a...nomy, he is the principal... AstroSat... project. ... ISRO in 2... space-... contin...

mation security and cyberph... ical systems security.

The awardees of biological sciences are Amit Singh fr... Indian Institute of Scien... Bengaluru, and Arun Kum... Shukla of IIT-Kanpur. Singh's works on infectious disea... with focus on HIV and tuber... losis. Shukla's research invol... ...use of protein biochemis... ...macology a...

The Indian...

Maharashtra Times Pune February 08, 2022, Pp. 7

देशात खगोलशास्त्र शिक्षणाची चार केंद्रे

शालेयस्तरावर अध्यापन पद्धतीचा विकास

म. टा. विशेष प्रतिनिधी, मुंबई

जगात खगोलशास्त्र शिक्षणाला पाठिंबा देणाऱ्या 'आंतरराष्ट्रीय ॲस्ट्रोनॉमिकल युनियन'च्या 'ऑफिस ऑफ ॲस्ट्रॉनॉमी फॉर एज्युकेशन'या उपक्रमांतर्गत भारतात चार प्रशिक्षण केंद्रांची स्थापना करण्यात येणार आहे. शालेयस्तरावर खगोलशास्त्र अध्यापन पद्धती विकसित करण्यासाठी ही केंद्रे काम करणार आहेत.

केंद्रीय शिक्षण मंत्रालयाने पुण्यातील 'आयुका' आणि मुंबईतील 'होमी भाभा विज्ञान शिक्षण केंद्र' यांच्या अंतर्गत या केंद्रांचे व्यवस्थापन होईल असे जाहीर केले...

केंद्रांमध्ये खगोलशास्त्र (अध्यापन/ शिकविण्याच्या) पद्धती ... माध्यमिक... भाषा ...

विद्यार्थी जोडले जाणार

हे केंद्र शालेयस्तरावर खगोलशास्त्र शिक्षणात औपचारिक संशोधनदेखील करणार आहे. विद्यार्थ्यांच्या मनातील खगोलशास्त्राशी संबंधित बोधीय भूदृश्य, सांकल्पिक सूचीसारख्या साधनांचा वापर करून पद्धतशीरपणे संशोधन केले जाईल. त्याच वेळी खगोलशास्त्रातील संकल्पना नकाशे तयार केल्यास अध्ययनाची दिशा अधिक चांगली समजून घेता येईल, असे होमी भाभा विज्ञान शिक्षण केंद्राचे अनिकेत सुळे यांनी सांगितले. या केंद्रांमुळे देशात खगोलशास्त्राविषयीचे अधिक ज्ञान उपलब्ध होईल याचबरोबर अधिकाधिक विद्यार्थी याच्याशी जोडले जाऊ शकतील, असा विश्वास व्यक्त होत आहे.

...ा आणि आत्मविश्वासाची ...ून घेणे, हे शिक्षक ...क्रमांच्या पुनर्रचनेसाठी ...ल, असे मत आयुकाचे ... व्यक्त केले.

Times of India Pune May 26, 2021 Pp. 6

IUCAA to webcast total lunar eclipse at 4.30pm today for sky enthusiasts

TIMES NEWS NETWORK

Pune: The first total lunar eclipse of 2021 on Wednesday visible in the North America, Central America, and parts of South America can be seen as a partial eclipse only in places in the northeast of India. Other areas, including Pune, do not fall in its path.

"The shadow of the earth on the moon can only be seen by that side of the earth where the sun-earth-moon alignment happens. In India, it will be around 5pm when the moon is mostly covered. We will only see it come out of the shadow by the time the earth rotates to bring the moon into view for us. People in the Americas and some countries in the Pacific Ocean will see it as a total lunar eclipse," Samir Dhurde, science educator and astronomer at the Inter-University Centre for Astronomy and Astrophysics in Pune, said.

When the earth, in the course of its revolution, comes in between the sun and the moon blocking the rays of the sun from reaching the moon directly, casting a shadow on the moon.

Director of Nehru Planetarium Arvind Paranjpye said the moon in Wednesday's lunar eclipse will also be a red moon and a blood moon.

"When the sun sets, the moon appears reddish because when the sun is in the horizon, the atmosphere scatters most of the blue light from the visible spectrum. The red part of the spectrum is the least scattered leading to a reddish appearance. The same will happen during the lunar eclipse. Blue light will be scattered while the least scattered red light will give a reddish tinge to the moon," Paranjpye said while advising people not to believe in superstitions associated with eclipses.

Aniruddha Deshpande, vice president of Jyotirvidya Parisanstha (JVP), the oldest association of amateur astronomers in India, said the last total lunar eclipse was visible on July 27, 2017 followed by a partial lunar eclipse on July 16, 2019.

WATCH IT IN HAWAII

> Enthusiasts can watch the live webcast of the total lunar eclipse from Hawaii where it will be full at 4.30pm IST on YouTube.com/IUCAAScipop/live

> An eclipse takes place a few hours after the moon reaches perigee, the position of the moon closest to earth in its orbit. The maximum eclipse tomorrow will be at 16:48:42 IST. The duration of the full eclipse will be 14 minutes.


File photo

> The next partial lunar eclipse visible from Pune will be on October 28, 2023 followed by a total lunar eclipse on September 7, 2025

Times of India, Pune February 03, 2022 Pp. 4

Intl Astronomical Union opens centre in IUCAA

SwatiShindeGole
@timesgroup.com

Pune: The International Astronomical Union (IAU) has established a new "branch office" of the Office of Astronomy for Education (OAE Centre India) at the Inter-University Centre for Astronomy and Astrophysics (IUCAA), in association with the Homi Bhabha Centre for Science Education (HBCSE), Mumbai.

The centre will focus on astronomy teaching methods and tools of assessment for middle and high-school students and teachers, along with language inclusivity.

A statement issued by IUCAA and HBCSE said th… focus of the work carrie… out in this new centre w… be on astronomy teachi… methods and tools of … sessment for middle- high-school students … teachers, along with la… age inclusivity.

"Although the as… my community has c… vely created a large r… of education resou… the last few years, …

TASKS TO BE TAKEN UP

- Development of a model curriculum that are relevant and sensitive to specific regions, cultures and languages of India, and various countries of Asia/Africa with similar learning environments
- It will develop teaching materials and strategies with a focus on the delivery of quality content even in low resource classrooms
- Local context specific teacher training programmes (in online as well as offline modes) introducing them to active learning models and evidence based teaching via astronomy, will also be taken up over the next few years

need for standardised tools … protocols to assess the … impact value of … as …

developed by OAE, but will also support initiatives in neighbouring countries that use common langua- … already hosts … for …

Maharashtra Times Pune March 1, 2021 Pp. 3

'ऑनलाइन' विज्ञानदिनाची जागतिक भरारी

आयसर, आयुका 'जीएमआरटी'च्या कार्यक्रमांना प्रतिसाद

म. टा. प्रतिनिधी, पुणे

प्रयोगशाळेबाहेर लागलेल्या आबालवृद्धांच्या रांगा नाहीत आणि विज्ञान प्रदर्शनामध्ये झडणाऱ्या चर्चाही नाहीत... यंदाच्या राष्ट्रीय विज्ञान दिनी पुण्यातील संशोधन संस्थांमध्ये रविवारी शुकशुकाट होता. मात्र, यंदाच्या 'ऑनलाइन' विज्ञान दिनालाही पुणेकर विज्ञानप्रेमींचा 'हाउसफुल्ल' प्रतिसाद मिळाला. आयसर, आयुका आणि 'जीएमआरटी' या फक्त या तीन संस्थांच्या 'ऑनलाइन' कार्यक्रमांना काही तासांत तब्बल साठ हजार जणांनी भेट दिली.

करोनामुळे असलेल्या मर्यादांमुळे शहरातील सर्व संशोधन संस्थांनी यंदाचा विज्ञान दिन ऑनलाइन साजरा केला. पुण्यातील इंडियन इन्स्टिट्यूट ऑफ सायन्स एज्युकेशन अँड रिसर्चच्या (आयसर, पुणे) विज्ञान दिनाच्या ऑनलाइन कार्यक्रमाला यू-ट्यूबवर दिवसभरात सुमारे चाळीस हजार जणांनी भेट दिली. जायंट मीटरवेव्ह रेडिओ टेलिस्कोपच्या (जीएमआरटी) ऑनलाइन कार्यक्रमात अकरा हजार, तर आंतर विद्यापीठ खगोलशास्त्र आणि खगोल भौतिकशास्त्र केंद्राच्या (आयुका) कार्यक्रमाला दिवसभरात दहा हजार जणांनी हजेरी लावली. पुण्यातील संस्थांच्या ऑनलाइन कार्यक्रमामध्ये फक्त पुणेकरच नाही, तर देशातील सर्व राज्ये आणि विदेशातूनही विज्ञानप्रेमी विद्यार्थी आणि नागरिक सहभागी झाले.

'आयसर, पुणे'चे अशोक रूपनेर म्हणाले, 'लॉकडाऊनच्या काळात आम्ही राबवलेल्या 'ऑनलाइन' कार्यक्रमांमुळे जगभरातील प्रेक्षक आमच्याशी आधीच जोडले गेले होते. विज्ञान दिनानिमित्त एकाच दिवशी वैज्ञानिक खेळण्यांचे प्रात्यक्षिक, विविध विषयांतील शास्त्रज्ञांची व्याख्याने, त्यांच्याशी संवाद, सायन्स फिल्म आदी वैविध्यपूर्ण उपक्रम राबविल्यामुळे सलग सात तास यू-ट्यूबवरील प्रेक्षकांची संख्या कायम राहिली. यंदा विद्यार्थ्यांना संस्थेला प्रत्यक्ष भेट देणे शक्य नसले, तरी या मर्यादेमुळे आमचा 'ऑनलाइन' उपक्रम मात्र ग्लोबल झाला.

दरम्यान, इंडियन. इन्स्टिट्यूट ऑफ ट्रॉपिकल मेटीओरोलॉजी (आयआयटीएम), राष्ट्रीय पेशी विज्ञान संस्था (एनसीसीएस), आघारकर संशोधन संस्था, भारतीय हवामानशास्त्र विभाग (आयएमडी) या संस्थांनी घेतलेली 'ऑनलाइन' व्याख्याने आणि परिसंवादांना विज्ञानप्रेमींचा रविवारी चांगला प्रतिसाद मिळाला.

व्हिडिओ स्पर्धेला प्रतिसाद

आयुकाच्या 'ऑनलाइन' कार्यक्रमांनाही विज्ञानप्रेमींचा मोठा प्रतिसाद लाभला. ज्येष्ठ खगोलशास्त्रज्ञ डॉ. जयंत नारळीकर, मंगलाताई नारळीकर आणि प्रा. सोमक रायचौधरी यांच्या ऑनलाइन प्रश्नोत्तरांच्या कार्यक्रमासाठी देशभरातील विद्यार्थ्यांकडून शेकडो प्रश्न जमा झाले होते. त्यांतील निवडक २५ प्रश्नांची उत्तरे या सत्रात देण्यात आली. नॅशनल सेंटर फॉर रेडिओ अॅस्ट्रोफिजिक्स (एनसीआरए) आणि आयुका यांनी स्वतंत्रपणे घेतलेल्या विज्ञान व्हिडिओ स्पर्धेलाही देशभरातून उत्स्फूर्त प्रतिसाद लाभला.

THE TIMES OF INDIA, PUNE
WEDNESDAY, JUNE 30, 2021

Neutron star-black hole collision G-waves spotted

Times News Network

Pune: Gravitational waves have been observed from a collision of a neutron star and a black hole for the first time by detectors from the LIGO-Virgo collaboration.

Till now, the gravitational waves (G-waves) had been gauged only from the collision of two black holes or two neutron stars, but never a hybrid combination.

The observations will help scientists understand the formation and relative abundance of such binaries, the behaviour of matter at extreme densities and probe the effects of systems under extreme gravity.

Such binaries of black hole and neutron stars will help scientists learn about the acceleration of the universe, Tarun Souradeep, LIGO-India spokesperson, said.

"With more detectors like the LIGO India detector coming up, we will have more accuracy in calculating the distances and hence the expansion rate," Souradeep added.

When massive cosmic bodies like black holes and neutron stars collide, ripples travel across the fabric of spacetime and are called gravitational waves. In this particular detection, the first collision event was detected on January 5, 2020, by the LIGO-Livingston and Virgo observatories and the second one was gauged on January 15 by three observatories _ LIGO-Livingston, LIGO-Hanford and Virgo, an official release said.

A tool called parameter estimation was used to understand the exact nature of the objects that collided over a billion years ago. It was found that the mass of the heavier object is in the range of the black holes as observed indirectly [illegible] ... pes w[illegible] ... ter c[illegible] ... of [illegible] ... ma[illegible] ... th[illegible] ... tists use match filtering to achieve this.

Parameswaran Ajith, associate professor from International Centre for Theoretical Sciences, said if they have models of expected signals, it is easier to extract them from noisy data like picking up words from our own language in a noisy crowd.

"This is because our brain ... "template" of known ... atches the au... ears.

INDIAN CONTRIBUTION

Indian researchers from the LIGO-India Scientific Collaboration have been a part of the research. Shasvath Kapadia from the International Centre for Theoretical Sciences in Bengaluru helped with the estimation of the neutron star and black hole merger rate, using a method he co-developed

› Estimating how often mergers of neutron stars and black holes occur within a surveyed volume of space (often referred to as the "merger rate") gives scientists clues to the origin and formation of these systems

› The two detected events give scientists bounds on the merger rate. Such events are estimated to occur between 2 to 250 times per year within a volume of space centred at the Earth, and spanning 1 gigaparsec cube (about 3 billion light years), an official release said

Times of India   Pune   February 26, 2021   Pp. 4

Science Day with IUCAA, IMD goes virtual this Sunday

Times News Network

Pune: The Science Day this year, which falls on Sunday, will be a virtual celebration as citizens can attend the talks, take a tour of the scientific institutions in the city, participate in online exhibitions and competitions.

All scientific institutions in the city have taken the virtual mode by creating YouTube channels and other platforms.

The Indian Institute of Science Education and Research (IISER), Pune, has planned various sessions for the entire day for students, teachers, science enthusiasts, parents, and [illegible] public ...

Centre for Astronomy and Astrophysics, all virtual programmes will be live-streamed on their YouTube channel. Short talks, public lectures, a virtual visit to the IUCAA's Girawali Observatory have been organised.

Citizens can also send their questions to IUCAA using Tweet #askiucaa which would be answered by astrophysicist Jayant Narlikar, Somak Raychaudhury, Surhud More and other eminent personalities.

Center for Science Education and Communication (Science Park) at Savitribai Phule Pune University had organised competitions on poems and story writing for teachers and the results will be announ[illegible] ... Besides, an ae[illegible] ... tour ... ssion ... iistry ... their ... ogical ... upload ... n inter- ... tion on ...

Sakal   Pune   March 1, 2021   Pp.2

विज्ञानोत्सवाला आंतरराष्ट्रीय कोंदण

भरगच्च कार्यक्रमांनी विज्ञान दिन उत्साहात

मी पृथ्वी सोडणार नाही : डॉ. नारळीकर

नवे बदल स्वीकारतोय

विश्वनिर्मितीच्या महाविस्फोट (बिग बँग) सिद्धांताच्या विरुद्ध 'स्थिर विश्वाचा सिद्धांत' (स्टेडी स्टेट) मांडला जातो. डॉ. नारळीकरांचे गुरू प्रा. फ्रेड हॉयल आणि त्यांच्या सहकाऱ्यांनी या सिद्धांतासंबंधी संशोधन केले होते. आजवर मिळालेले पुरावे हे महाविस्फोटाच्या सिद्धांताला पूरक आहेत. त्या तुलनेने स्थिर विश्वाचा सिद्धांताबाबत कमी पुरावे मिळाले आहेत. यासंबंधी विचारलेल्या प्रश्नाला उत्तर देताना डॉ. नारळीकर म्हणाले, "नवीन संशोधन करताना वैचारिक खुलेपणा स्वीकारायला हवा. १०० वर्षांपूर्वीचे भौतिकशास्त्रातील सिद्धांत आणि आजचे सिद्धांत यात मोठा बदल झाला आहे. विश्वाबद्दल अजूनही आपल्याला फार कमी माहीत आहे. कोणताही सिद्धांत नाकारणे सहज शक्य नाही. मात्र, त्याच्या समर्थनार्थ आपल्याला जास्त पुरावे गोळा करावे लागतील. बिग बँगची स्पष्टता देणाऱ्या 'रेड शिफ्ट' बद्दल पुनर्विचार करण्याची गरज आहे. कारण त्यासंबंधीही नवे संशोधने समोर येत आहे. निश्चितच नवे बदल आम्ही स्वीकारत आहोत."

आयुका, सावित्रीबाई फुले पुणे विद्यापीठ परिसर : विज्ञान दिनी विद्यार्थी आणि नागरिकांनी गजबजून जाणारे आयुकाचे हे प्रांगण, यंदा कोरोनामुळे निर्मनुष्यच होते.

IUCAA ACADEMIC CALENDAR

Annual Events at IUCAA

2021

Refresher Course on Astronomy and Astrophysics
Date: May 10 - June 11, 2021

Introductory Summer School on Astronomy and Astrophysics
Date: May 10 - June 11, 2021

Foundation Day
Date: December 29, 2021

2022

National Science Day
Date: February 28, 2022

Events at IUCAA

2021

An advanced course on pulsar astrophysics
Date: January 25 - April 03, 2021 (Online)
Coordinators: D. J. Saikia | Prakash Arumugasamy

Introductory course on astronomy and astrophysics for college teachers
Date: January 27 - April 09, 2021 (Online)
Coordinators: D. J. Saikia, Gazi Ahmed (Tezpur University), Rupjyoti Gogoi (Tezpur University), Biman Nath (Gauhati University)

BRICS Astronomy Working Group (BAWG2021) meeting (Online)
Date: May 19 - 20, 2021
Coordinators: R. Gupta

Advanced Astrosat Data Analysis workshop
Date: June 15 - 30, 2021 (Online)
Coordinators: Jayashree Roy | M. Shahalam

Mini workshop on online pedagogy and evaluation
Date: June 30, 2021 (Online)
Coordinators: D. J. Saikia | G. Ambika (IISER, Tirupati)

Astronomical data analysis using Python
Date: November 08, 2021 - December 18, 2021
Coordinators: D. J. Saikia | Yogesh Wadadekar (NCRA, Pune)

IUCAA - NCRA Radio Astronomy Winter School - 2021
Date: December 20, 2021 - January 01, 2022
Coordinators: Prakash Arumugasamy | Jameer Manur | Subhashis Roy (NCRA, Pune) | Ruta Kale (NCRA, Pune)

Events Outside IUCAA

2021

Workshop of Solar Astrophysics
Date: August 24, 2021
Place: Fergusson College, Pune (Online)
Coordinators: Raka Dabhade | Durgesh Tripathi

GuruDhwani
Date: September 01, 2021 - April 09, 2022
Place: Fergusson College, Pune (Online)
Coordinators: Raka Dabhade(FC College Pune) | Avinash Deshpande | D. J. Saikia

Research In Astronomy: Opportunitie And Challenges -VII
Date: September 8 - 10, 2021
Place: Online
Coordinators: Sheelu Abraham | Jeena K. | R. Misra

Introductory Workshop in Astronomy and Astrophysics
Date: December 18 - 19, 2021
Place: University of Kashmir, Srinagar
Coordinators: Naseer Iqbal | R. Misra

2022

North-East Meet of Astronomers (NEMA-VII)
Date: January 27 - 29, 2022
Place: R. G. University, Itanagar, Arunachal Pradesh (Hybrid mode)
Coordinators: Heisnam Shanjit Singh | R. Misra

AWARDS AND DISTINCTIONS

[2021- 2022]

- **Sukanta Bose**,
  on being elected as
  Fellow, Indian Academy of Sciences

- **Debarati Chatterjee**,
  on receiving the
  Poster contest award at NuSym 2021 -
  International Symposium on Nuclear Symmetry Energy,
  October 20, 2021, along with
  PhD student **Suprovo Ghosh** (IUCAA)

- **Sanjeev Dhurandhar**,
  on being elected as *Fellow*,
  Indian National Science Academy (INSA),
  Delhi.

- **Jayant V. Narlikar**,
  on being conferred Doctor of Science
  (Honoris Causa)
  from Dr. D. Y. Patil Vidyapeeth,
  Pune

- **Kanak Saha**,
  on being conferred with the
  Shanti Swarup Bhatnagar Award
  for the Physical Sciences
  by CSIR, New Delhi

Late **Professor Thanu Padmanbhan**
Lifetime Achievement Award
(Kerala Sasthra Puraskaram)
of Government of Kerala, 2021
for his life time contributions
in Theoretical Physics.

RESEARCH GRANTS AND FELLOWSHIPS

Dipankar Bhattacharya

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

Sauradeep Bhattacharya

- DST – INSPIRE Faculty Fellowship.

Sukanta Bose

- LIGO India TDCB and DAE
- LIGO India SEED and DST

Subhadeep De

- DST grant for the project: Quantum Information Technologies with ion-trap and optical-lattice devices of Interdisciplinary Cyber Physical Systems.
- DAE Board of Research in Nuclear Sciences
- I-HUB Chanakya Fellowship

Sanjeev Dhurandhar

- NASI Senior Scientist Platinum Jubilee Fellowship.

AjitKembhavi

- Grant for the Pune Knowledge Cluster.

RanjeevMisra

- University of Southampton - UK Global Challenge Research Fund for Pune Knowledge Centre

Sanjit Mitra

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

Dipanjan Mukherjee

- Indo French Centre for the Promotion of Advanced Research Grant for the project: Resolving the impact of AGN feedback on gas and star formation through simulations and observations.

A.N. Ramaprakash

- Participation Grant in Thirty Metre Telescope Project.
- ISRO Grant for the Design, Development, Assemble, Test, Calibrate the Solar Ultraviolet Imaging Telescope (SUIT) payload for Aditya – L1 Mission.
- Infosys Foundation Grant for Resurgent Caltech – IUCAA Collaboration for Advanced Instrument Development and Scientific Discoveries.
- ISRO – ISAC Grant.
- Institute of Plasma Physics Crete WALOP N
- South African Astronomical Observatory
- Institute of Arizona LBT1

Kanak Saha

- Grant for the project: Exploring the Nature of Lyman Continuum Emitting Sources in the AstroSat – UV Deep Field.

Varun Sahni

- DST J.C. Bose Fellowship.


DEVAYANI

PUNE KNOWLEDGE CLUSTER

About Pune knowledge Cluster

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

Vision

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

Mission

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

Key Achievements (since inception in July 2020)

- PKC has raised over Rs. 5 CR in the form of grants and CSR funding from organizations like Rockefeller Foundation, Hindustan Unilever, Cummins Foundation, Persistent Foundation, Schlumberger, Lenovo India, BASF Chemicals India, and the University of Southampton for its various projects.
- PKC has built partnerships with 60 organizations (national and international) and signed MoUs with 18 organizations including academia, R&D labs, industries, NGOs, and incubation centers.

PKC Focus Areas

I. Health

PKC's Health vertical aims to build collaborations across academic and industry, NGOs, and Govt departments in generating data critical for public health decisions such as serosurveys, clinical, immunological, and environmental surveillance etc., and creating an epidemiological database with comprehensive health information for Pune and access to real-time data. Projects supported under PKC's health vertical align with the **Integrated Disease Surveillance Project (IDSP)** and the **National Health Mission**.

Projects: PKC manages 5 ongoing projects and has completed 1 project on COVID-19.

- COVID-19 Sero-survey, COVID-19 Genomic Surveillance, COVID-19 Environmental Surveillance, COVID-19 Data Collection and Analysis (Supported by Rockefeller Foundation)
- COVID-19 Long Term Immunogenicity Study (Supported by Hindustan Unilever)
- COVID-19 Clinical Database

Partners: Projects are implemented in a collaborative manner between the hospitals, R&D labs and city administration. Key partners include – IISER Pune, NCL Pune, BJMC, KEM, Symbiosis, Genepath, Noble Hospital

Key Future plans: Infectious Disease Platform - Building a platform for multi-institutional collaborations for data-driven policies for infectious diseases.

II. Sustainability & Environment

Aligned to the **National Action Plan on Climate Change**, PKCs Sustainability and Environment vertical currently has three priorities:

- **Technology-driven Urban Forestry Programs** to preserve and improve tree cover in Pune City. PKC is working to create technology platforms to automate tree census, improve citizen engagement in tree plantation and adoption and build a computational platform for carbon sink estimation.
- **Sustainable Afforestation Program**: Mission Prakriti is a PKC project which aims to develop an 1172 ha. Self-sustaining (socially, financially, and environmentally sustainable) Biodiversity Park on degraded reserve forest for carbon sequestration and biomass generation.
- **Water Action Plan for Pune Metropolitan Region**: Aligned to the **National Water Mission**, PKC is preparing a sustainable water Management Plan for the Pune district, comprising of comprehensive information on priority issues, and available resources (human, technical and financial), and mapped solutions. A digital decision-making support system will also be created using time-series and real-time absolute data, GIS maps, and analytics.

Work with local administration: PKC works actively with PMC and Pune Zilla Parishad officials to serve as a knowledge partner for technology evaluation, project feasibility studies, and creating plans for implementing water conservation, and bio-energy projects in Pune and its surrounding villages.

Partners: PMC, Pune Smart City, CEE India, WRCS, Gaia the Earth Foundation, Genesys, Maharashtra Forest Department, Samuchit Environment

Key Future plans:

- **Center for Water** – Building a Center for water management, technology deployment, and policy in collaboration with Water Valley, Denmark
- **CoE for Carbon Sequestration & Renewable Energy** – Building a center of excellence focused on increasing urban/peri-urban and rural vegetation cover for carbon sequestration, developing technology-based plantation models and citizen engagement programs, piloting technologies for biofuels production

III. Sustainable Mobility

PKC's Sustainable Mobility vertical aims to apply scientific and technical tools to address the rapidly growing and changing mobility requirements of the city. We wish to support the development of sustainable solutions toward carbon-neutral transportation.

Working towards the **Smart City Mission** of GoI, the Pune City administration is encouraging and enabling sustainable modes of mobility in the city. In this regard, PKC has the following programs in the pipeline.

- **Vehicle E-Waste Recycling** –Projects are being conceptualized with technology providers and the auto industry to pilot novel technologies for vehicle E-waste recycling at the city level through public-private partnership models.
- **Charging Infrastructure Mapping using Pune Digital Twin** – In partnership with TCS Pune Digital Twin, PKC wishes to map and plan locations for EV charging infrastructure in the city.

Partners: Automotive Research Association of India (ARAI), Center for Materials for Electronics Technology (CMET), C4i4, Society of Automotive Engineers

IV. BIG Data & Artificial Intelligence

This vertical enables the development of various AI-driven platforms for basic and applied research. Large-scale citizen science programs are being developed to involve citizens in analyzing BIG scientific data to foster scientific temper. One such program is called One-Million Galaxies where 450+ citizens have analyzed over 1 GB of data (images of galaxies) on PKC's platform. PKC is also trying to build collaborative projects between BIG Data and AI experts, chemists, and biologists to encourage inter-disciplinary research.

Partners: CODATA, IUCAA, Univ. of Southampton, IIA Bangalore, HBCSE Mumbai, Nehru Planetarium Mumbai, Jawaharlal Nehru Planetarium Bangalore, Jyotirvidya Parisanstha Pune, Khagol Vishwa Pune

V. Capacity Building

Aligned with the **Skill India Mission**, the capacity-building vertical of PKC aims to provide new opportunities to students, young researchers, and professionals to improve their knowledge base and acquire advanced skills through the following programs

- Interdisciplinary Training Programs & Courses – Contemporary skill-building and knowledge enhancement
- Citizen centric science talks by experts

PKC has conducted over 35 training programs, talks and webinars involving over 96 mentors with 2500+ beneficiaries.

STEM Education: Aligned with the **National Education Policy 2020**, PKC's STEM education vertical focuses on promoting STEM education through technology-enabled training programs for school teachers and students, scholarship programs for women in STEM, gamification of learning, and setting up of STEM Labs.

Projects: PKC has 2 ongoing STEM projects – Teach with Tech (sponsored by Lenovo India) and WEnyan – a mentoring and scholarship program for women in chemistry and sustainability (sponsored by BASF Chemicals India)

Partners: Icertis, Infosys Springboard, IBM, DY Patil Engineering, SPPU, District Institute of Education and Training, Pune Zilla Parishad, Agarkar Research Institute, CODATA, Persistent Systems, Serum Institute of India.

Key Future plans:

CoE for STEM Education: Centre with a focus on innovation in school education, gamification in learning, STEM labs, girl education, and Math Circles.

Cosmology and Structure Formation

No H_0 tension in Braneworld Cosmology

Local measurements of the Hubble parameter H_0, based on a distance ladder treatment, appear to indicate a somewhat higher value of this quantity than that inferred from fitting ΛCDM to the cosmic microwave background (CMB) data. This tension currently stands at about the $4.4\,\sigma$ level.

In the context of evolving dark energy, two different approaches have been advanced to minimize the H_0 tension (for a detailed review of all existing solutions. The first one focuses on the physics prior to recombination explores late-time physics, particularly the impact of non-ΛCDM cosmologies such as models with interacting dark sector and phantom behaviour Our focus in the present paper will be on the second approach, i.e., models that exhibit phantom behaviour of dark energy.

CMB measurements determine the spacing between the acoustic peaks of the angular power spectrum,

$$\theta_s = \frac{r_s^*}{D_A(z_*)} \,, \tag{1}$$

very accurately at redshift $z_* \simeq 1100$. Here, r_s^* is the comoving sound horizon at the epoch of last scattering (we adopt the normalization $a_0 = 1$),

$$r_s^* = \int_0^{t_*} c_s(t)\frac{dt}{a(t)} = \int_{z_*}^{\infty} c_s(z)\frac{dz}{H(z)} \,, \tag{2}$$

where c_s is the sound speed, given by

$$c_s(z) = \frac{c}{\sqrt{3}\sqrt{1+\frac{3\Omega_{0\mathrm{b}}}{4\Omega_{0\gamma}(1+z)}}} \,, \tag{3}$$

and $D_A(z_*)$ is the comoving angular diameter distance to the last scattering surface,

$$D_A(z_*) = \int_0^{z_*} \frac{dz}{H(z)} \,. \tag{4}$$

In a spatially flat ΛCDM cosmology, one has

$$H(z) = H_0 \left[\Omega_{0\mathrm{m}}(1+z)^3 + \Omega_{0\mathrm{r}}(1+z)^4 + \Omega_\Lambda\right]^{1/2} \,, \tag{5}$$

where $\Omega_{0\mathrm{m}}$ includes the contribution from dark and baryonic matter, and $\Omega_{0\mathrm{r}}$ includes the contribution from photons as well as other possible relativistic matter such as neutrino's.

Although both r_s^* and $D_A(z_*)$ explicitly contain H_0 in the denominator, a careful examination reveals that they depend on H_0 differently (for a fixed Ω_{0m}). This is because the parameter $\Omega_{0\mathrm{r}}$ is determined in cosmology in the combination $\Omega_{0\mathrm{r}}h^2$ (here, $h \equiv H_0/100\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$), which makes $\Omega_{0\mathrm{r}}$ substantially H_0-dependent, unlike the other two parameters Ω_{0m} and Ω_Λ. As $H(z)$ increases with z, the primary contribution to (2) and (4) comes from redshifts near the lower limits of the respective integrals. Since the integration in (4) starts from $z = 0$, one can neglect the contribution from the radiation term in $H(z)$ at low redshifts, thus $D_A(z_*)$ roughly scales as H_0^{-1}. On the other hand, r_s^* depends on H_0 differently as the integration in (2) starts from $z_* \simeq 1100$ (the value of z_* is almost unaffected by any reasonable variation in H_0). At these high redshifts, one cannot neglect the contribution from the radiation part in (5), which is substantially H_0-dependent, as explained above. Therefore, the Hubble parameter no longer scales as H_0; rather $H(z) \propto H_0^n$, where $0 < n < 1$ at redshifts $z \simeq 1100$. Furthermore, c_s depends on the ratio $\Omega_{0\mathrm{b}}h^2/\Omega_{0\gamma}h^2$. Since $\Omega_{0\gamma}h^2$ is fixed from CMB measurements and one can assume independent constraint on $\Omega_{0\mathrm{b}}h^2$ from, say, big bang nucleosynthesis (BBN) c_s is almost insensitive to H_0 (a mild dependency comes from the minute variation of z_* with H_0). One can estimate numerically that r_s^* roughly scales as $H_0^{-0.5}$, which results in $\theta_s \propto H_0^{0.5}$ approximately (for a fixed Ω_{0m}). Therefore, an increase in H_0 also raises the value of θ_s.

Since θ_s is fixed from CMB measurements, one way of compensating the increment (due to a larger locally measured value of H_0) is to reduce r_s^*. As demonstrated by (2), the quantity r_s^* can be reduced by slightly increasing $H(z)$ (by about 10%) just before recombination. Early dark energy does precisely this; however, in these models, the mean constraint on the Hubble parameter does not shift much to the higher values when one considers combination of all datasets including the CMB polarisation data. (A shift in H_0 can also be achieved by assuming the existence of primordial magnetic fields enhancing the recombination rate, thereby reducing the Hubble tension.)

An alternative means of ameliorating the H_0 tension is to reduce the value of $E(z) \equiv H(z)/H_0$ at lower redshifts, $z \ll z_*$. This increases $D_A(z_*)$ in (4) and therefore compensates for the increase in θ_s brought about by a larger value of H_0. This can be done more or less phenomenologically in models of evolving or dynamical dark energy. It is interesting in this respect that a smaller value of $E(z)$ at low/medium z (compared to that of ΛCDM model) is a *generic* (and quite incidental) feature of a certain type of braneworld cosmology. Specifically, the model with one extra dimension and with induced gravity on the brane has two branches of cosmological solutions, one of which (so-called 'normal branch') exhibits this property. On this branch, the effective equation of state (EoS) of dark energy is phantom-like, $w_{\rm eff} < -1$, for which reason it was also termed 'phantom brane'. One can envisage that the H_0 tension will be alleviated in this braneworld scenario.

Indeed, **Satadru Bag**, **Varun Sahni**, Arman Shafieloo and Yuri Shtanov have shown that the phantom brane can accommodate higher values of H_0, preferred by recent local measurements, while satisfying CMB constraints.

A simulated annealing approach to parameter inference with expensive likelihoods

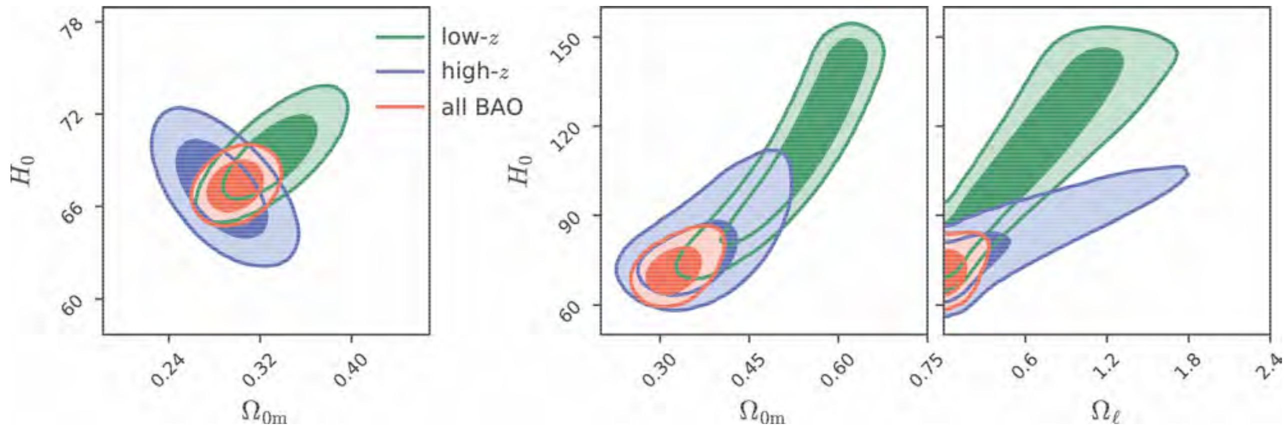
Aseem Paranjape has developed a new approach to parameter inference targeted on generic situations where the evaluation of the likelihood (i.e., the probability to observe the data given a fixed model configuration) is numerically expensive. Inspired by ideas underlying simulated annealing, the method first evaluates $\chi^2 = -2\ln\mathcal{L}$ on a sparse sequence of Latin hypercubes of increasing density in parameter (eigen)space. The semi-stochastic choice of sampling points accounts for anisotropic gradients of and rapidly zooms in on the minimum of χ^2. The sampled χ^2 values are then used to train an interpolator which is further used in a standard Markov Chain Monte Carlo (MCMC) algorithm to inexpensively explore the parameter space with high density, similarly to emulator-based approaches now popular in cosmological studies. Comparisons with example linear and non-linear problems show gains in the number of likelihood evaluations of factors of 10 to 100 or more, as compared to standard MCMC algorithms. As a specific implementation, the author has publicly released the code PICASA: Parameter Inference using Cobaya with Anisotropic Simulated Annealing, which combines the minimizer (of a user-defined χ^2) with Gaussian Process Regression for training the interpolator and a subsequent MCMC implementation using the publicly available COBAYA framework. Being agnostic to the nature of the observable data and the theoretical model, this implementation is potentially useful for a number of emerging problems in cosmology, astrophysics and beyond.

Quasi-adiabatic relaxation of haloes in the IllustrisTNG and EAGLE simulations

The dark matter content of a gravitationally bound halo is known to be affected by the galaxy and gas it hosts. Premvijay Velmani and **Aseem Paranjape** have characterised this response for haloes spanning over four orders of magnitude in mass in the hydrodynamical simulation suites IllustrisTNG and EAGLE using their default astrophysical models and respective gravity-only counterparts. They show that commonly employed quasi-adiabatic relaxation models, which treat the relative change in radius $r_f/r_i - 1$ of a spherical dark matter shell as a function of only the relative change in its mass $M_i/M_f - 1$, do not describe the measured response of most haloes in IllustrisTNG and EAGLE. Rather, the relaxation ratio r_f/r_i additionally explicitly depends upon halo-centric distance $r_f/R_{\rm vir}$ for haloes with virial radius $R_{\rm vir}$, being very similar between IllustrisTNG and EAGLE. They also identify a previously unmodelled effect, likely driven by feedback-related outflows, in which shells having $r_f/r_i \simeq 1$ (i.e., no relaxation) have M_i/M_f different from unity. They present simple fitting functions in the quasi-adiabatic relaxation framework that accurately capture the dark matter response over the full range of halo mass and halo-centric distance we explore. They also explore the dependence of this response on several halo and galaxy properties beyond total mass. Their results are immediately applicable to a number of semi-analytical tools for modelling galactic and large-scale structure (baryonification schemes, rotation curves, etc.). These results can be extended to build a deeper physical understanding of the connection between dark matter and baryons at small scales.

Semi-analytic modelling of the Lyman-alpha forest using the Lognormal approximation

Bhaskar Arya, T. Roy Choudhury (NCRA), **Aseem Paranjape** and Prakash Gaikwad (MPI, Heidelberg) have revisited the Lognormal approximation for modelling the spatial distribution of the Lyman-alpha forest and its sensitivity to astrophysics and cosmology. Using MCMC techniques to compare the Lognormal approximation with the Sherwood hydrodynamical simulations, they find that the Lognormal model provides a faithful representation of the z = 2.5 inter-galactic medium in terms of the Lyman-alpha transmitted flux probability



(a) ΛCDM

(b) minimal phantom brane

Figure 1: The 68% and 95% confidence levels on the cosmological parameters are shown separately considering the low-z BAO data (green), the high-z BAO data (blue) and all the BAO data (red), in conjunction with SNe+BBN prior. The left panel shows the results for the ΛCDM model whereas the results for the minimal phantom brane are shown in the two figures of the right panel.

density function and power spectrum. These results are a first step towards establishing the utility of the Log-normal model as a cosmological tool.

Astrobiology

The astrobiology experiment by **Jayant V. Narlikar**, and collaborators is progressing. The next phase of balloon experiment is under consideration of ISRO.

Observational Astronomy and Extragalactic Astronomy

The Subaru HSC weak lensing mass-observable scaling relations of spectroscopic galaxy groups from the GAMA survey

Galaxies such as our own Milky Way are part of groups of galaxies. Such galaxy groups are some of the most abundant structures in the Universe. The different properties of galaxy groups such as the total luminosity of such groups in stars, the velocity dispersion of galaxies in these groups are correlated with the total dark matter mass around galaxy groups. These correlations are expressed as scaling relations between galaxy groups and their halo masses. In research work led by student **Divya Rana** and **Surhud More**, along with collaborators from Japan, Australia and the US, these scaling relations for galaxy groups were measured with the best precision so far.

To study the dark matter content of galaxy groups in the Universe using weak lensing, they utilized galaxy shape catalogue from the first-year data release of the Subaru Hyper Suprime-Cam (HSC) survey to study the dark matter content of galaxy groups in the Universe using weak lensing. The signal was modelled using a Bayesian halo model framework to infer the halo mass distribution of our groups binned in the two different observable properties of galaxy groups. They obtained a 5 per cent constraint on the amplitude and 7 percent constraint on the slope of both the scaling relation between halo mass and group luminosity, and that between halo mass and velocity dispersion.

Extragalactic Astronomy

Observing correlations between dark matter accretion and galaxy growth: testing the impact of galaxy mass, star formation indicator, and neighbour colours

Do galaxies whose dark matter halos accrete fresh gas also have higher star formation rates? In research work by **Surhud More** and collaborators from the University of Arizona, reported previously, they had shown that star formation activity may not be correlated with fresh accretion for isolated Milky Way-mass galaxies. In this follow up research work, they investigate their conclusions further by carrying out three different tests using data from the Sloan digital sky survey. For the first test, they use satellite galaxies with different colours (blue star forming galaxies, or red galaxies which have stopped forming stars), trace different populations which fall in to the halo. For the second test they used indicators which are sensitive to star formation rate over longer time scales. Lastly they also tested if the ir conclusions hold for central galaxies with stellar mass larger than the Milky Way.

All these tests bolster their previous conclusion that the probability that star formation rate is positively correlated with mass accretion rate is quite low. This result is most consistent with models where processes such as gas recycling dominate star formation in galaxies at late times.

Galactic Astronomy

Subaru Hyper Suprime-Cam Survey of Cygnus OB2 Complex

Low-mass star formation inside massive clusters is crucial to understand the effect of cluster environment on processes like circumstellar disc evolution, planet, and brown dwarf formation. In this research carried out by Saumya Gupta, a student of IUCAA associate Jessy Jose at IISER Tirupathi, and **Surhud More**, they present observations of the young massive association of Cygnus OB2. This cluster has many massive stars which can be used to study the effect of extreme environmental conditions on its extensive low-mass population. They carried out the deepest and widest optical photometry of 1.5 degree diameter region centred at Cygnus OB2 in r2, i2, z, and Y-filters, using Subaru Hyper Suprime-Cam (HSC). They confirmed the presence of a distinct pre-main sequence branch by statistical field subtraction of the central 18 arcmin region and found that the median age of the region is about 5 million years with an average disc fraction of ˜9 per cent. They presented catalogs of sources belonging to this region with masses ranging from ˜0.01 – 0.17 times mass of the Sun. This deeper HSC catalogue will serve as the groundwork for further studies on this prominent active young cluster.

Extreme emission like galaxies such as Green peas and Blueberries in the local universe are the potential candidates for understanding the nature of star-forming galaxies that reionized the early universe. Green pea and Blueberry galaxies are compact, low-mass, metal-poor starburst systems. Despite their close proximity to us, we know little about their spatially resolved properties - they remain unresolved. In this project, we report the detection of a low-surface brightness (LSB) stellar disk with very old stellar population using the SDSS-IV MaNGA integral field spectroscopy observation. The evidence for the old stellar population comes from a 5σ detection of MgIλ5173 absorption line in both under the Blueberry system and in the extended region. We show that this was not possible had we used the SDSS fibre spectra only (old stellar component remains undetected). Even with the IFU data, the detection has become possible only after stacking the spectra in either region. Based on our analysis of the MaNGA data, we derived kinematics (especially binning required) for the full galaxy and show that the disk is mildly rotating with $V/\sigma\tilde{1}$. This work and our ongoing ones suggest an intriguing thread connecting Blueberries with LSB galaxies.

This project has been published in the Astrophysical Journal (ApJ), 2022

Extragalactic Astronomy

Giant radio quasars

Giant radio sources (GRSs) are radio-loud active galactic nuclei (AGNs) with a projected linear size greater than or equal to 700 kpc. When the GRSs are associated with galaxies, they are known as giant radio galaxies (GRGs), whereas GRSs with quasar hosts are known as giant radio quasars (GRQs). They are the largest single objects in the Universe and pose a number of challenging astrophysical questions. In order to understand GRQs and their properties, Mousumi Mahato, including **D.J.Saikia**, **Somak Raychaudhury** and collaborators have compiled all known GRQs ("the GRQ catalogue"), and a subset of small (size $<$ 700 kpc) radio quasars (SRQs) from the literature. In this process, they have found 10 new GRQs which they include in the GRQ catalogue. They have carried out a systematic comparative study of GRQs and SRQs, using optical and radio data, and found that the GRQs and SRQs have similar spectral index and black hole mass distributions. But SRQs have higher radio core power, core dominance factor, total radio power, jet kinetic power and Eddington ratio compared to GRQs. On the other hand, when compared to GRGs, GRQs have higher black hole mass and Eddington ratio. The high core dominance factor of SRQs is an indicator of them lying closer to the line of sight than GRQs. They also find a correlation of the accretion disc luminosity with the radio core and jet power of GRQs, which provides evidence for disc-jet coupling. Lastly, they find the distributions of Eddington ratios of GRGs and GRQs to

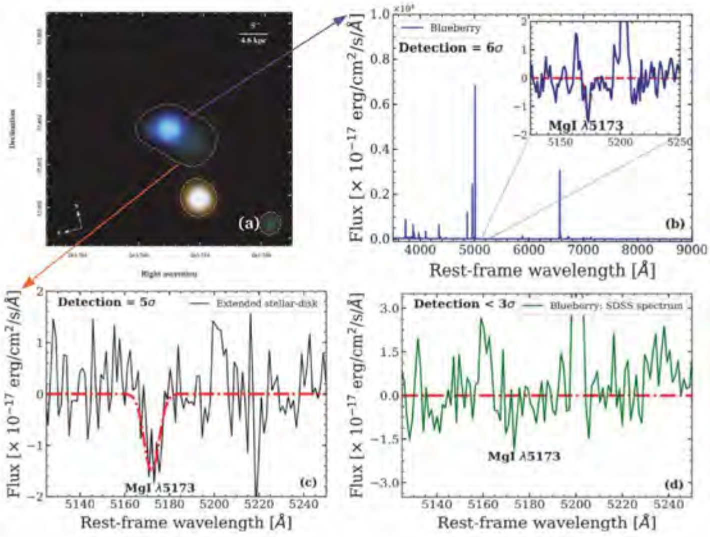


Figure 2: (a) The gri-band color composite image of SHOC 579. The dashed line shows the contour at 3σ level above the background. The inner dashed circle of size 3" (diameter) marks the blueberry region. (b) The stacked full observed spectrum within a 3" diameter. The inset represents the detection of the MgIλ5173 absorption line from the blueberry region. (c) The detection of the MgI λ5173 absorption line obtained through the stacked spectra from the extended diffuse stellar-disk region. (d) Null detection of the MgIλ5173 absorption line in the observed SDSS spectrum taken over the central 3" diameter on the blueberry region. In each spectrum, the red dashed line represents the fitted continuum + Gaussian models over the observed MgIλ5173 absorption feature. In panel (d), the Gaussian model is not fitted as the detection of the Mg I λ5173 absorption feature is below 3σ

be bi-modal, similar to that found in small radio galaxies (SRGs) and SRQs, which indicate that size is not strongly dependent on the accretion state. Using all of these, they provide a basic model for the growth of SRQs to GRQs.

Nuclear radio emission in nearby galaxies

To understand the nature of nuclear radio emission in nearby galaxies Ranieri Baldi and collaborators have combined optical [OIII] line emission, robust black hole (BH) mass estimates, and high-resolution e-MERLIN 1.5-GHz data, from the LeMMINGs survey, of a statistically-complete sample of 280 nearby, optically active (LINER and Seyfert) and inactive (HII and Absorptionline galaxies [ALG]) galaxies. They suggest different origins for the nuclear radio emission for the different optical classes. Below a black hole mass of $\sim 10^{6.5} M\odot$ stellar processes from non-jetted HII galaxies tend to dominate. Above this value, accretion driven processes tend to dominate for the active galaxies which include radio-quiet/loud galaxies with low-ionization nuclear emission line regions (LINERs), Seyfert galaxies and jetted HII galaxies. Jetted HII galaxies may host weakly active black holes. Fuel-starved black holes and recurrent activity account for ALG properties. They suggest that specific accretion-ejection states of active black holes determine the radio production and the optical classification of local active galaxies.

Compact steep-spectrum radio sources

Compact steep-spectrum radio sources are defined to be less than 20 kpc in size so that these are well within the confines of their host galaxies, and interact with the interstellar medium as the jets propagate outwards. There are three suggestions for their small sizes: (i) they are young objects which will evolve into larger-sized radio-loud active galaxies; (ii) they are confined to small sizes by a dense interstellar medium and (iii) they may be transient or intermittent sources. Our current understanding of this class of sources including their effects on theirhost galaxies and evidence of recurrent activity from observations across the electromagnetic spectrum has been reviewed by C. P. O'Dea and **D. J. Saikia**. Most appear to be young objects although there is evidence of jet disruption by interaction with the interstellar medium and also of recurrent jet activity. The review closes with a discussion of open questions and prospects for the future.

Galactic and Extragalactic Astronomy

(a) Emission lines from X-ray illuminated accretion disc in black hole binaries

X-ray observations of black hole X-ray binaries show prominent Fe K emission lines at $6-7$ keV energy band and Compton hump at $\sim 20-30$ keV which indicates that the material above the accretion disc is being illuminated by the hard X-ray source. Several differing models have been proposed in the literature to explain this emission phenomenon, however, most of these models use the incident spectra from the phenomenological power-law model to illuminate the gas, and do not take into account the detailed accretion solution and the effects of flow parameters and its geometry.

S. Mondal, **T.P. Adhikari**, and Singh, B. Chandra (2021) made a synergy between the two component accretion flow model and photoionization simulations to explain the X-ray spectra of black hole binaries, mainly focused on the Fe emission spectra at $5.5-7.2$ keV. The authors showed that the equivalent width (EW) of Fe emission decreases with the increase in disc accretion rate and increases with the column density of the material (see Fig. 3 left). This is due to the fact that the incident spectrum becomes softer with increase in accretion rate and hence less number of hard photons participate in line emission. Additionally they also checked the dependence of emission on the halo accretion rate and demonstrated that, increasing halo accretion rate increases the number of high energy emission lines in the spectrum. Also, the lines shape become complex as abundant number of hard X-ray photons are available for the ionization which triggers the thermal instability. The authors also found that the Fe line EW tends to decrease with increase in ionization parameter until low ionization region; however, it sharply increases in higher ionization regime $\xi > 10^3$, and at $\xi > 10^4$, EW decreases as a wider part of disc becomes fully ionized (see Fig. 3 right).

(b) X-ray timing and spectral variability properties of blazars S5 0716 + 714, OJ 287, Mrk 501, and RBS 2070

Blazars are seen as an extreme class of radio-loud active galactic nuclei, characterized by high luminosity, rapid variability in flux and polarization, and broadband continuum emission. Blazar emission mainly consists of the Doppler boosted non-thermal emission from the relativistic jets. The variability of blazar fluxes is strong across the entire electromagnetic spectrum with the variability timescales varying from minutes to several decades. The multi-wavelength variability properties of blazars usually can be ascribed to both the relativistic jets and accretion disc based models. However, the details of the processes leading to such multi-wavelength and multi-timescale variability are still under discussion.

Recently M. Mohorian, G. Bhatta, **T.P. Adhikari,** et al. (2022) explored statistical properties of the X-ray variability in the blazars S5 0716+714, OJ 287, Mkn 501 and RBS 2070 using the archival observations from the *XMM-Newton* telescope between the period 2004–2018. Several methods of timing and spectral analyses including fractional variability, minimum variability timescale, power spectral density (PSD) analyses and flux distribution were performed. In this work, the authors showed that the sources are moderately variable within the intra-day timescale. Three of the four sources exhibited a clear bi-modal pattern in their flux distribution revealing possible indication of two distinct flux states, that is, hard and soft flux states. Furthermore, they also investigated the spectral shapes of the sources using single power-law, broken power-law, log-parabolic and black-body+log-parabolic models (the latter only for OJ 287), and found that for most of the observations log-parabolic model was the best fit. The power spectral density analysis revealed the variable nature of PSD slopes in the source light curves. The results of this analysis could indicate the non-stationary nature of the blazar processes on intra-day timescales. The observed features can be explained within the context of current blazar models, variability arising in the relativistic jets.

(c) Variable mass accretion and failed wind explain changing look phenomena in NGC 1365

Changing-look active galactic nuclei (CLAGNs) exhibits a complex behaviour in their X-ray spectral shape and the variation in the line-of-sight column-density. As of now, the physical mechanisms responsible for these variations are unclear. In the recently accepted paper for publication in the journal A & A, Mondal, S.; **Adhikari, T. P.**; et al. (2022) studied the spectral properties of a CLAGN NGC 1365 using combined *XMM-Newton* and *NuSTAR* observations to understand its

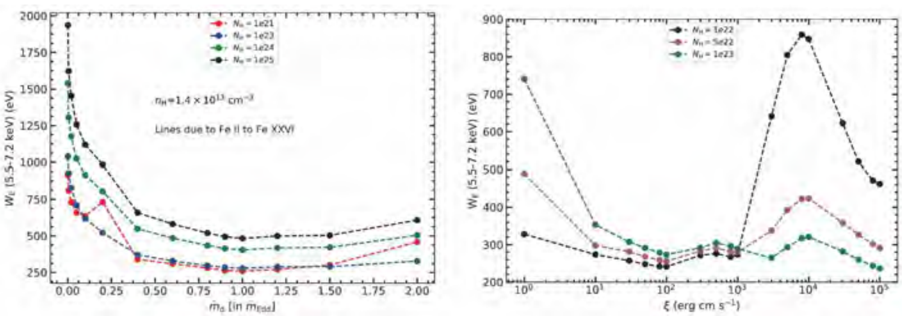


Figure 3: (left) Equivalent width $W_{\rm E}$ of Fe line integrated in the energy range $5.5 - 7.2$ keV as a function of disc rate $\dot{m}_d$. (right) Variation of equivalent widths as a function of ionization parameter ξ.

CL behavior. The authors have utilized the results from photoionization simulations and found that the variable absorption column density correlates with the mass accretion rate and the geometry of the corona. The derived wind velocity was sufficiently low compared to the escape velocity to drive the wind away from the disc for the epochs during which column densities were high. This suggests that the high and variable absorption can be due to failed winds from the disc. From spectral fitting of the combined observational data, the authors estimated the mass of the central black hole to be $4.38 \pm 0.34 - 4.51 \pm 0.29 \times 10^6$ $\rm M_{Sun}$ consistent with earlier findings. This study construed that the changing accretion rate, which is a fundamental physical quantity and the geometry of the corona are driving the CL phenomena in NGC 1365.

MALS SALT-NOT survey of MIR-selected powerful radio-bright AGN at $0 < z < 3.5$

The MeerKAT Absorption Line Survey (MALS; PIs: **Neeraj Gupta** and **R. Srianand**) is one of the ten large surveys being carried out with the MeerKAT radio telescope in South Africa. The main goal of the project is to better characterize the evolution of cold atomic and molecular gas in galaxies at $0 < z < 2$. Over 2014 - 2017, MALS team carried out an ambitious spectroscopic survey using SALT (180 hrs) and the Nordic Optical Telescopes (6 nights) to build a purely infrared-selected sample of radio-loud quasars (RLQs) at $z > 1.5$ and define the MALS footprint. The 180 hrs of SALT observing time for this project were contributed by IUCAA, the Rutgers University and South African collaborators. The following figure shows SALT spectra of five representative AGN from the survey. Different emission lines based on which the redshift was determined are identified in the figure. The error spectra are shown in red in each panel. The hashed regions mark the spectral range falling in the CCD gaps. Inset in the top most panel shows the double peak $[OIII]$ $\lambda5007$ profile. In the bottom panel an example of AGN without detectable emission lines is shown.

A paper describing the survey is recently accepted for publication in ApJ (Gupta et al. 2022, ApJ, 929, 108). In short, the dust-unbiased sample of powerful radio-bright (> 200mJy at 1.4GHz) from the survey consists of 250 AGN (median z = 1.8) showing emission lines, 26 with no emission lines, and 27 without optical counterparts, and covers AGN parameter space which is underrepresented even in the Sloan Digital Sky Survey. All the spectra from the survey will be shared with the community through https://mals.iucaa.in/ a MALS data release scheduled in 2022. The MALS footprint, a major objective of the survey, based on the SALT-NOT survey is shown in the adjoining figure.

The SALT-NOT sample is optically fainter compared to the quasars used to search for high HI column density (damped Lyman-alpha) absorbers in the past. The detection of five intervening (redshift path $\tilde{9}.3$) and two proximate DLAs from the subset survey is slightly excessive compared to the statistics based on optically selected quasars. This hints towards the presence of dusty AGN that may have been missed in optically selected samples of AGN. The follow-up of a blind search of radio absorption lines using the upgraded Giant Metrewave Telescope (uGMRT) has allowed first constraints on the cross-section of HI and OH absorptions lines at $z > 2$ (Gupta et al. 2021, ApJ, 255, 28). The SALT-NOT survey is leading to various multi-wavelength follow-up observations using MeerKAT, uGMRT, VLT, VLBA, and VLA to address fundamental issues related to AGN and cold gas evolution.

HI gas playing hide-and-seek around a powerful FRI type quasar at $z \sim 2.1$

The observations of absorption lines associated with active galactic nuclei (AGN) provide crucial insights into the different feedback processes operating in AGN host galaxies. By revealing the chemical composition, clumpiness, and physical conditions in denser and colder phases of the gas at parsec to kiloparsec scales from the nucleus, these absorption line studies can bridge the gap in our understanding of how the ubiquitous halo gas and circumnuclear disk fuel the AGN activity. Gupta et al. recently used the Robert Stobie Spectrograph on SALT and the Very Long Baseline Array to discover a curious case of high HI column density absorber that exhibits strong HI 21-cm absorption at radio wavelengths but is absent at optical wavelengths.

The milliarcsecond-scale radio continuum observations of this quasar M1540-1453 ($zem = 2.104 \pm 0.002$) show Fanaroff Riley class I morphology caused by the interaction with dense gas within 70 pc of the AGN. Interestingly, while there are indications for the presence of absorption from low-ionization species like Fe II, Si II, and Si III in the optical spectrum, the expected strong damped Lyα absorption is not detected at the redshift of the H I 21 cm absorber (SALT spectrum presented above). In comparison to typical high-z quasars, the Lyα emission line is much narrower. The "ghostly" nature of the H I Lyα absorber partially covering the broad-line region of extent 0.05 pc and the detection of widespread H I 21 cm absorption covering the diffuse radio source (extent > 425 pc) imply the presence of a large clumpy H I halo, which may have been blown by the jet-interstellar medium (ISM)interaction. The adjoining cartoon depicts a quadrant of M1540-1453 embedded in a clumpy ISM. The quasars optical sight line (dashed line) may not intercept infalling high-N(H I) clouds. In comparison, extended radio emission (> 425 pc) from the lobes will be intercepted by several such clouds, producing the broad redshifted H I 21 cm absorption line. The extent of the H I halo and radio emission could be as large as 10 kpc. The results from this have been recently published in ApJ as Gupta et al. 2022, ApJL, 927, L24.

The quasar M1540-1453 was discovered through an ambitious spectroscopic survey using SALT (180 hrs) and the Nordic Optical Telescopes (6 nights) to build a purely infrared-selected sample of radio-loud quasars (RLQs) at $z > 1.5$ and define the footprint of the MeerKAT Absorption Line Survey (MALS). The MeerKAT Absorption Line Survey (MALS; PIs: **N. Gupta** and **R. Srianand**) is one of the ten large surveys being carried out with the MeerKAT radio telescope in South Africa. In the coming years, the SALT-NOT survey and MALS are expected to address various fundamental issues related to AGN and cold gas evolution.

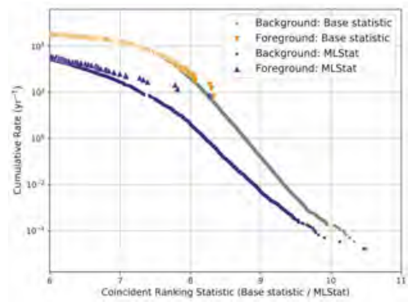


Figure 4: This Figure shows how MLStat reduces the noise background, increasing the significance of the "foreground" statistic containing real events. In the figure, the statistic values for the event GW151216 (marked by stars) are by design nearly equal for the standard and MLStat based methods, but due to the reduction in noise background the detection significance increases manyfold. [PHYS. REV. D 104, 064051 (2021)]

Gravitational Waves

1. Improving significance of binary black hole mergers in Advanced LIGO data using deep learning : Confirmation of GW151216: **Shreejit Jadhav**, Nikhil Mukund (AEI, Hannover), Bhooshan Gadre (AEI, Potsdam), **Sanjit Mitra** and Sheelu Abraham (IUCAA Associate) added a Machine Learning (ML) based vetoing statistic (MLStat) to `PyCBC`, LIGO-Virgo-KAGRA (LVK) collaboration's official analysis pipeline, to search for compact binary coalescences (CBCs). While different methods have been proposed to achieve a similar goal, this is the first ML based analysis scheme that could successfully recover all the events listed in the official LVK catalog, GWTC-1, obtained from LIGO-Virgo's first two observation run data. The authors also confirmed the detection of an event, GW151216, which was missed by the official LVK pipeline, though detected by other analysis. They also performed a full injection study to show that the sensitivity of the search increases by an impressive amount of $\sim 10\%$ for lower mass black holes and $\sim 30\%$ for higher mass black holes.

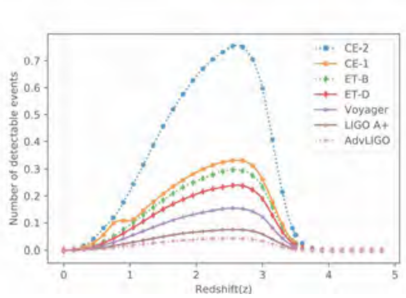


Figure 5: This Figure shows the estimated rates for hyperbolic encounters of black holes detectable by the present and future ground based detectors as a function of red-shift. The parameters used to obtain these estimates are based on recent simulations performed by reputed international groups. The details can be found in the paper (MNRAS 508, 5064?5073 (2021)).

2. Hierarchical search: **Kanchan Soni**, Bhooshan Gadre (AEI, Potsdam), **Sanjit Mitra**, and **S. V. Dhurandhar** applied the Hierarchical Search scheme for detecting CBCs developed recently on Advanced LIGO's first two observation run data and recovered all the events in official catalog GWTC-1 that were detected by the standard pipeline. The highlight is that, they get a whopping factor 20 speed up in computation, retaining the approximate detection significance for each event. They also showed using an injection study that the hierarchical search statistically has the same sensitivity as the conventional flat search.

3. Hyperbolic encounters of Black Holes: The ground based gravitational wave detectors have so far detected coalescence of compact binaries. However, compact stars can also interact without getting bound in a closed orbit. **Sajal Mukherjee**, **Sanjit Mitra** and Sourav Chatterjee (TIFR), using conservative and realistic conditions from latest published simulations, showed that hyperbolic encounters of black holes in globular clusters may be detectable by future ground based detectors. This will be an exciting discovery and can provide additional information to estimate the number of back holes in the universe. They also show that the detection rates are weakly dependent on the minimum detectable signal-to-noise ratio (SNR) in a detector due to the complex scaling relations, hence even if the detectors are able to observe only high SNR events, the probability of observation remains significant.

4. Upper-limit on Anisotropic SGWB from the first two observing run of advanced LIGO incorporating full noise-covariance matrix: Deepali Agarwal (IUCAA), Jishnu Suresh (ICRR, Tokyo), **Sanjit Mitra** and Anirban Ain (INFN, Pisa), have set upper-limits on skymaps of anisotropic stochastic gravitational wave background (SGWB) in pixel basis incorporating the full pixel-to-pixel noise covariance matrix (NCVM). This was not done in the standard LVK analysis for two reasons, the NCVM was challenging to compute before the advent of `PyStoch` (a very fast SGWB mapmaking pipeline developed at IUCAA which is now the official LVK pipeline for the same purpose), and it is ill-conditioned, so sophisticated techniques would be necessary to incorporate it in the analysis. The authors propose different schemes using multiple forms of the Likelihood function to achieve this and also perform an extensive injection study to compare those. They find that while the upper limit maps looks quite different for different schemes, they are still consistent, that is for less than 5% of the pixels, the conservative 95% upper-limit fall below the injected value. This exercise validates the simplistic scheme used in the LVK analysis in pixel basis using only variances (the diagonal of the NCVM, though in spherical harmonic basis a regularised full NCVM was used). They recommend using this simple scheme also in the All-Sky-All-Frequency (ASAF) analysis.

5. Component separation of anisotropic SGWB from advanced LIGO data: An anisotropic SGWB can be a superposition of multiple astrophysical and cosmological components. Jishnu Suresh (ICRR, Tokyo), **Deepali Agarwal** and **Sanjit Mitra** have jointly set upper-limits on anisotropic SGWB for different spectral components using advanced LIGO's O1, O2 and O3a data. While a stochastic background has not yet been detected, such analyses would likely be applied to data immediately after the first detection.

Matrix Representation of Time-delay interferometry

An upcoming space based detector of gravitational waves is the Laser Interferometric Space Antenna (LISA), a joint project of NASA and ESA. Since the space-craft are freely floating, it is an unequal arm interferometer and the laser frequency noise is not cancelled in a round trip. Cancellation of laser frequency noise is a necessary requirement for LISA to attain the requisite sensitivity for detecting gravitational waves. Time-delay interferometry (TDI) is a technique which linearly combines data from the three arms with appropriate time-delays, so that laser frequency noise is suppressed. M. Tinto, **S. Dhurandhar** and P. Joshi had previously shown that this problem can be translated into the language of algebraic geometry. They showed that the TDI form a module of syzygies over a polynomial ring - first defined by Hilbert in 1890.

They have proposed an alternative matrix based scheme for time-delay interferometry. We show that the original TDI scheme is just a matrix representation of the abstract operators - in fact, we explicitly establish the homomorphism. The advantage is that the matrix based approach naturally adapts to time-varying arm-lengths because in this case the operators do not commute and matrices are naturally non-commutative. They have applied this scheme to LISA.

Hierarchical search strategy in searching compact binary coalescences in the Advanced LIGO's first two observing runs

One important idea that needs investigation is employing hierarchical algorithms in gravitational wave searches. Such strategies save in the computational cost in searching for the signals, such as, compact coalescing binary stars. Saving on computational cost will free up CPU time for searches of other astrophysical sources.

The hierarchical search involves the following steps. In the first stage the search is performed by matched filtering the coarsely sampled data with a coarse template bank, in order to look for candidate events or triggers. These candidates events are then followed up with a finer search in the neighbourhood of the trigger. In this way, enormous computational cost savings are possible without any loss in sensitivity. Here **Kanchan Soni**, Bhooshan Gadre, **Sanjit Mitra** and **Sanjeev Dhurandhar** report the first successful implementation of the hierarchical search as a PyCBC-based production pipeline which performs a complete analysis of the Laser Interferometer Gravitational Wave Observatory (LIGO) observing runs. They analyze Advanced LIGO's first and second observing run data and recover all the events detected by the PyCBC (flat) search in the first GW catalog, GWTC-1, published by the LIGO-Virgo collaboration, with nearly the same significance. In the analysis, they get an impressive factor of 20 reduction in the computational cost compared to the flat search. With a standard injection study, they show that the sensitivity of the hierarchical search remains comparable to the flat search within the error bars.

Optimal chi square vetos applied to real data from LIGO detectors

S. Choudhary, P. Joshi, S. Bose and S. Dhurandhar The traditional chi square veto has been applied to the gravitational wave data with fair amount of success. However, this test is ad hoc and is not guaranteed to be optimal. In this work, S. Choudhary, P. Joshi, **Sukanta Bose** and **Sanjeev Dhurandhar** construct an optimal chi square test for glitches in the data which can be modelled as sine gaussians. Such glitches are ubiquitous in the data. The method for constructing any chi square has been fully discussed in our previous work on unified chi squares (S. Dhurandhar et al 2017). The optimal chi square is constructed the following way: First, the parameter space of sine-Gaussians is adequately sampled and a vector space spanned by these sampled vectors is constructed. By applying singular value decomposition, the space is whittled down to a much lower dimensional subspace which best approximates the original space of the sampled glitches, thus reducing the degrees of freedom of the chi square being constructed. This procedure eventually leads to the required optimal chi square for sine-Gaussian glitches. It is now being applied to the real data from the LIGO detectors.

Non-observation of gravitational wave (GW) microlensing to probe the nature of dark matter

One of the biggest puzzles in modern cosmology is the existence of dark matter, which constitutes most of the matter in the universe. If a significant fraction of dark matter is in the form of compact objects, they will cause microlensing effects in the GW signals observable by LIGO and Virgo detectors. In collaboration with an international team of researchers, Apratim Ganguly developed a method to constrain the fraction of compact dark matter to be less than $\simeq$ 50-80 % in the mass range $10^2 - 10^5 M\odot$ from the (non-)observation of microlensing signatures in the LIGO-Virgo observing runs.

These modest constraints will be significantly improved in the next few years with the expected detection of thousands of binary black hole events, providing a new avenue to probe the nature of dark matter.

A study to show the need for lensing templates for future LVK observing runs

In collaboration with Aditya Vijakumar (ICTS-TIFR) and Ajit Kumar Mehta (AEI Potsdam), **Apratim Ganguly** has worked on a project investigating the detection and parameter estimation challenges of Type-II

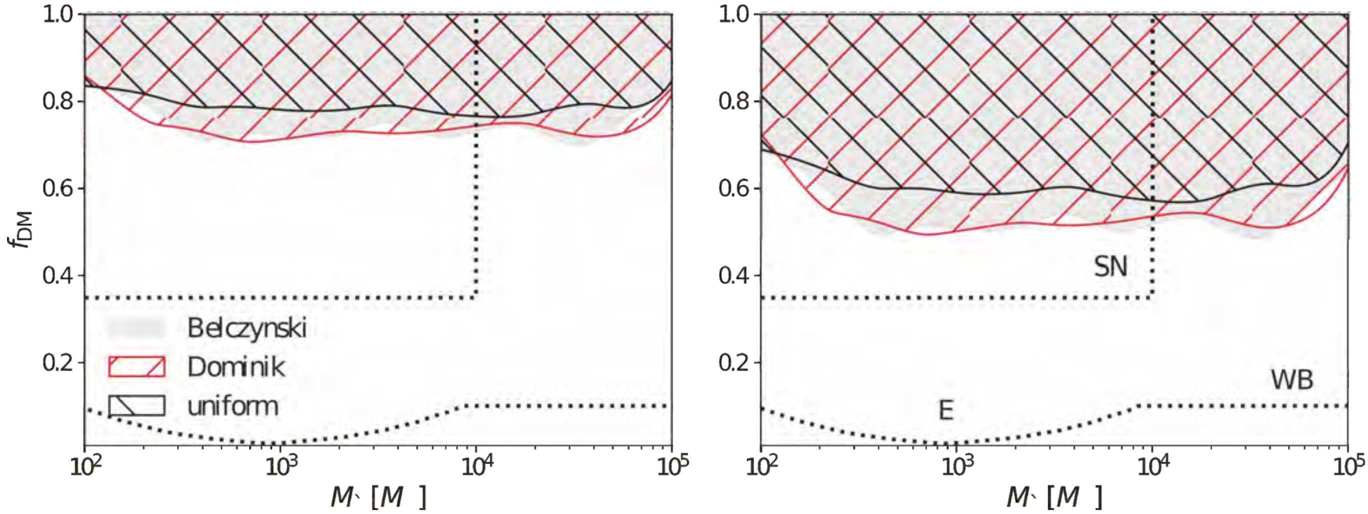


Figure 6: 90% upper limits on fDM obtained from the O1, O2 and O3a events, assuming monochromatic mass spectrum for MACHOs (lens mass shown in the horizontal axis). In each panel, three different exclusion regions correspond to three assumed models of the redshift distribution of binary black holes. The dashed lines show some of the existing constraints from the microlensing of supernovae (SN) and from the stability of wide binaries (WB) and a star cluster in the galaxy Eridanus II (E).

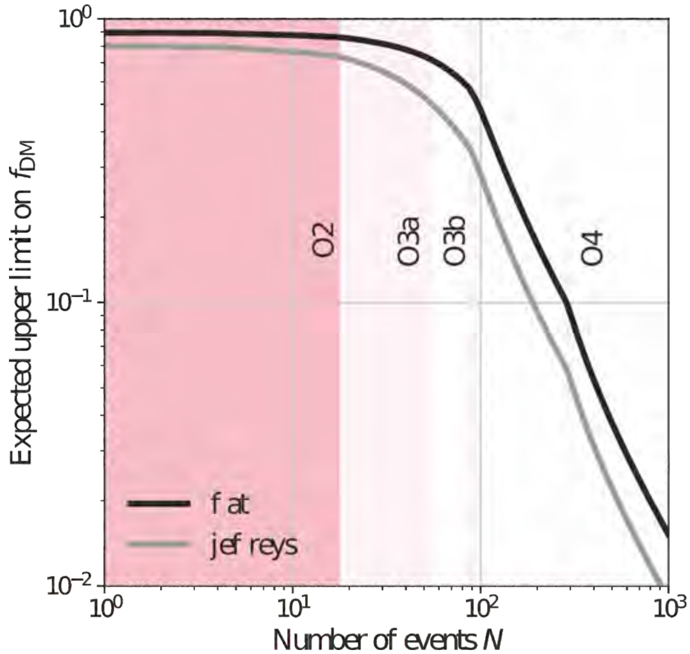


Figure 7: Upper bounds on f_{DM} expected from future observing runs, shown as a function of the cumulative number of detected binary black hole events (for lens mass $10^3 M\odot$).

lensed binary black hole signals. Type-II lensed GW signals introduce additional distortions in the strains of the BBH signals depending on various morphologies.

We investigated the potential applicability of these distortions in helping identify Type-II signals from a single detection. We also investigated the systematic biases that could arise in the inference of their parameters if they are unknowingly recovered with gravitational-wave templates that do not take the distortion into account. We show in the figure below that the lensing distortions will allow us to confidently identify Type-II images for highly inclined binaries: at network signal-to-noise ratio (SNR) $\rho = 20(50)$, individual Type-II images should be identifiable with log Bayes factor $\ln \mathcal{B} > 2$ for inclinations $i > 5\pi/12(\pi/3)$.

Testing Einstein's theory of relativity with gravitational waves

GW detected by the LIGO, Virgo and Kagra (LVK) detectors provide an ideal opportunity to test general relativity (GR), and any deviations thereof, in a 4 strong-field regime. Ten different tests were performed by the LVK collaboration to look for such deviations but all results were consistent with GR.

Apratim Ganguly, in collaboration with Aditya Vijaykumar and P. Ajith from ICTS-TIFR, carried out the inspiral-merger-ringdown consistency test on events to check the consistency of final masses and spins inferred from the inspiral and merger-ringdown parts of the gravitational wave signal.

Gravitational lensing of gravitational waves

Just as electromagnetic waves, GWs can also be lensed by matter inhomogeneities between the source and the observer. In the first half of the third observing run (O3a), the LVK collaboration searched for lensing signatures in their gravitational data. Though the comprehensive study of the data has uncovered no compelling evidence for gravitational lensing of detected events, it was possible to predict how frequently lensing occurs and determine how even the absence of detectable lensing effects already improves our knowledge of the compact binary merger rate in the distant universe. The collaboration also demonstrated how the absence of detection of stochastic gravitational waves from the early Universe improves our knowledge of the rate of lensing.

Anupreeta More and **Apratim Ganguly** were key contributors of this paper in terms of leading and reviewing multiple analyses as well as in preparing the

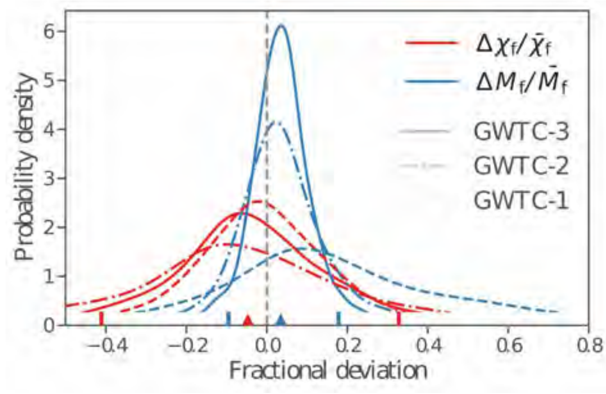


Figure 9: Fractional deviations between the mass (blue) and spin (red) from the inspiral and post-inspiral parts of the gravitational waveform inferred from GWTC-3 are compared against the results from the previous analyses (GWTC-1 and GWTC-2). The grey vertical line shows the GR value of zero and the results show excellent consistency with GR.

manuscript

Finding quadruply imaged quasars with machine learning. I. Methods:

Strongly lensed quadruply imaged quasars (quads) are extraordinary objects. They are very rare in the sky – only a few tens are known to date – and yet they provide unique information about a wide range of topics, including the expansion history and the composition of the Universe, the distribution of stars and dark matter in galaxies, the host galaxies of quasars, and the stellar initial mass function. Finding them in astronomical images is a classic "needle in a haystack" problem, as they are outnumbered by other (contaminant) sources by many orders of magnitude. To solve this problem, **Anupreeta More** and collaborators developed state-of-the-art deep learning methods and trained them on realistic simulated quads based on real images of galaxies taken from the Dark Energy Survey, with realistic source and deflector models, including the chromatic effects of microlensing. The performance of the best methods on a mixture of simulated and real objects is excellent, yielding area under the receiver operating curve in the range 0.86 to 0.89. Recall is close to 100% down to total magnitude $i \sim 21$ indicating high completeness, while precision declines from 85% to 70% in the range $i \sim 17 - 21$. The methods are extremely fast: training on 2 million samples takes 20 hours on a GPU machine, and 10^8 multi-band cutouts can be evaluated per GPU-hour.

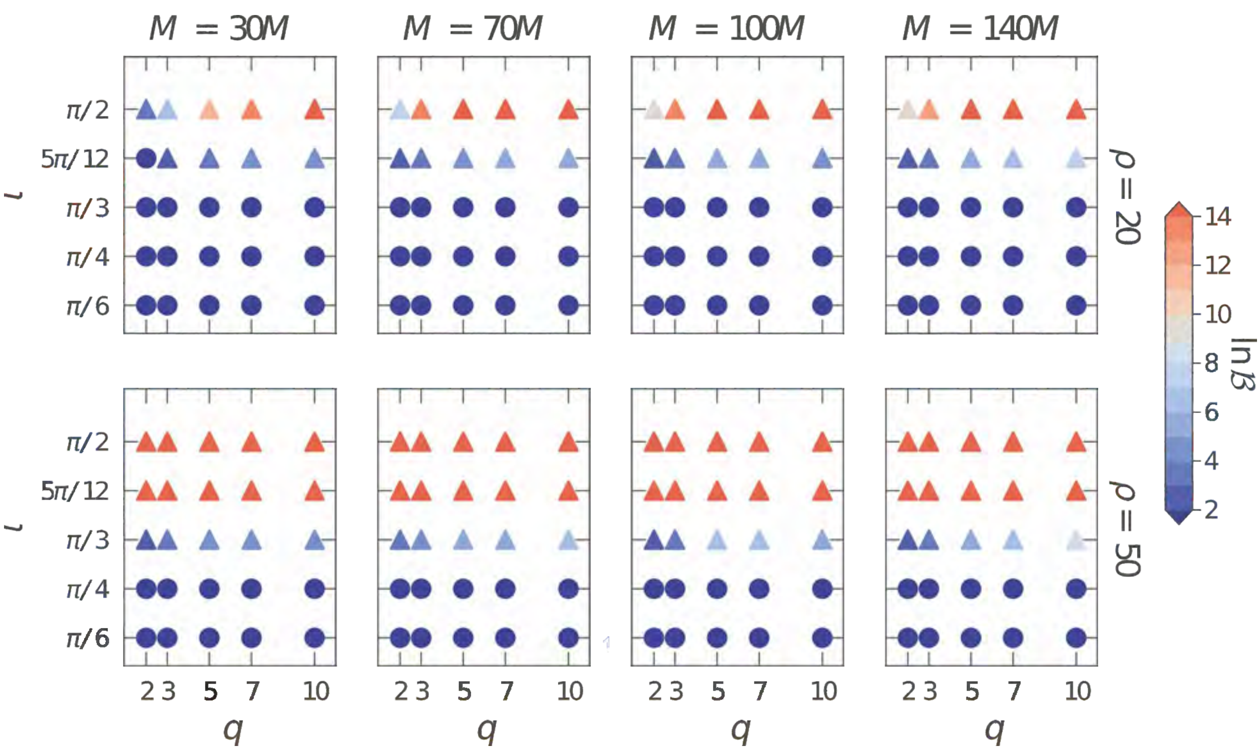


Figure 8: Type-II lensed BBH injections with a network SNRs $\rho = 20$(upper row) and $\rho = 50$ (bottom row) shown in the l - q plane for different total masses. The color bar shows the log Bayes factor between the Type-II and the Type-I recoveries. Injections which cross our threshold of $\ln\mathcal{B} > 2$ are plotted using triangles (i.e., distinguishable image types) while the others are plotted using circles

The speed and performance of the method pave the way to apply it to large samples of astronomical sources, bypassing the need for photometric pre-selection that is likely to be a major cause of incompleteness in current samples of known quads. **Reference: Akhazhanov, A., More, A., et al. 2022**

Improved statistic to identify strongly lensed gravitational wave events:

As the number of detected gravitational wave sources increases with increased sensitivity of the gravitational wave observatories, observing strongly lensed pairs of events will become a real possibility. Lensed GW events will have very accurately measured time delays and magnification ratios. Suppose we identify the lens system corresponding to a GW event in the electromagnetic domain and also measure the redshifts of the lens and the host galaxy; in that case, we can use the GW event to constrain important astrophysical parameters of the lens system. As most lensing events have image separations that are significantly smaller than the GW event localization uncertainties, we must develop diagnostics that will aid in the robust identification of such lensed events. **Anupreeta More and Surhud More** defined a new statistic based on the joint probability of lensing observables that can be used to discriminate lensed pairs of events from the unlensed ones. To this end, simulations of lensed GW events were carried out to infer the distribution of the relative time delays and relative magnifications sub-divided by the type of lensed images. This distribution was compared to a similar one obtained for random unlensed event pairs (see Fig. 10). Our statistic can improve the search pipelines' existing ranking approach to down-select event pairs for joint parameter estimates. The distributions obtained can further be used to define more informative priors in joint parameter estimation analyses for candidate lensed events.

Reference: More A., More S., 2021

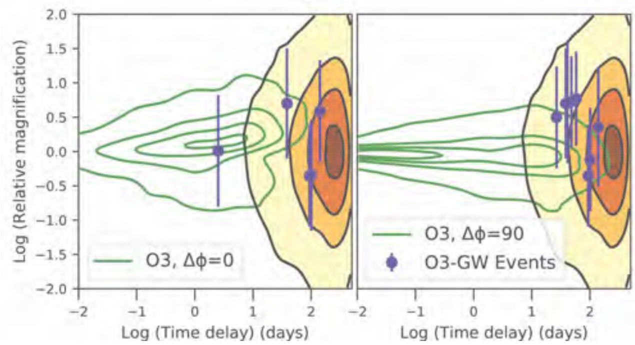


Figure 10: Time delay and magnification distributions are shown divided by the phase differences. Images of the same type i.e. $\Delta\phi = 0$ are on the left and those of distinct type i.e. $\Delta\phi = \pi/2$ are on the right. Except one, all of the other real GW events are consistent with coming from unlensed population.

HOLISMOKES. VI. New galaxy-scale strong lens candidates from the HSC-SSP imaging survey:

Anupreeta More and collaborators have carried out a systematic search for galaxy-scale strong lenses in multiband imaging from the Hyper Suprime-Cam (HSC) survey. The automated pipeline, based on realistic strong-lens simulations, deep neural network classification, and visual inspection, is aimed at efficiently selecting systems with wide image separations (Einstein radii $\sim 1.0-3.0$"), intermediate redshift lenses ($z \sim 0.4-0.7$), and bright arcs for galaxy evolution and cosmology. The gri images of all 62.5 million galaxies in HSC Wide with i-band Kron radius > 0.8" were classified to avoid strict pre-selections and to prepare for the upcoming era of deep, wide-scale imaging surveys with Euclid and Rubin Observatory. Over 200 promising lens candidates were discovered. probable lenses with either spatially-resolved multiple images or extended, distorted arcs. In addition, 88 high-quality candidates that were assigned lower confidence in previous HSC searches and recovery of 173 known systems in the literature was also reported. These results demonstrate that, aided by limited human input, deep learning pipelines with false positive rates as low as $\sim 0.01\%$ can be very powerful tools for identifying the rare strong lenses from large catalogs, and can also largely extend the samples found by traditional algorithms. **Reference: Cañameras R., ... More A., et al., 2021**

High Energy Astrophysics

Using the AstroSat Target of Opportunity (ToO) observations, along with two XMM-Newton observations in 2015 (pre-outburst) and 2018 June (peak outburst), **Prakash Tripathi** and **G. C. Dewangan** revealed rare spectral transition in a changing-look active galaxy

NGC1566. They found that the X-ray power law, the soft X-ray excess, and the accretion disk components showed extreme variability during the 2017-2018 outburst of the active galaxy. Especially, the soft excess was negligible in 2015 before the outburst, increased to a maximum level by a factor of ¿200 in 2018 June, and reduced dramatically by a factor of about 7.4 in 2018 August and became undetectable in 2018 October. The accretion rate relative to the Eddington rate increased from 0.1% (2015) to 5% (2018 June) and then decreased to 1.5% (2018 August) and 0.3% (2018 October). Thus, NGC 1566 made a spectral transition from a high soft-excess state to a negligible soft-excess state at a few percent of the Eddington rate. The soft excess is consistent with warm Comptonization in the inner disk that appears to have developed during the outburst and disappeared toward the end of the outburst over a timescale comparable to the sound-crossing time. The multiwavelength spectral evolution of NGC 1566 during the outburst is most likely caused by the radiation pressure instability in the inner regions of the accretion disk in NGC 1566.

Tripathi and **Dewangan** further studied multiwavelength spectral changes in the changing-look AGN NGC1566 using observations performed with XMM-Newton, Swift and NuSTAR space missions at five different epochs.

They found that at high-flux levels the soft X-ray excess and the disk emission both provided the seed photons for thermal Comptonization in the hot corona, whereas at low-flux levels, where the soft excess was absent, the pure disk emission alone provided the seed photons. The electron temperature of the corona increased from 22 to 200keV with the decreasing numbers of seed photons from 2018 June to 2019 August. At the same time, the optical depth of the corona decreased from 4 to 0.7, and the scattering fraction increased from 1% to 10%. These changes were interpreted as the structural changes in the hot corona that grew in size and became hotter with the decreasing accretion rate during the declining phase.

Alex Markowitz, K. Nalewajko, G. Bhatta, **G. C. Dewangan**, et al. reported results from a 4-d coordinated multiwavelength campaign on the highly peaked blazar (HBL) Mkn 421 in 2019 January. They obtained X-ray data from AstroSat, BVRI photometry with the Whole Earth Blazar Telescope (WEBT), and TeV data from First G-APD Cherenkov Telescope and explored short-term multiwavelength variability in this HBL. The X-ray continuum was rapidly variable on time-scales of tens of ks. Fractional variability amplitude increaseed with energy across the synchrotron hump, consistent with previous studies; Markowitz et al. interpreted this observation in the context of a model with multiple cells whose emission spectra contain cutoffs that follow a power-law distribution. They also performed time-averaged and time-resolved (time-scales of 6 ks) spectral fits that revealed time-resolved the usual hardening when brightening behaviour. The broad-band SED is modelled well with a standard one-zone leptonic model, yielding jet parameters consistent with those obtained from previous SEDs of this source.

Swadesh Chand, **G. C. Dewangan**, P. Thakur, **P. Tripathi** and V. K. Agrawal performed comprehensive temporal and spectral study of the newly discovered X-ray transient MAXI J1803-298 using an AstroSat target of opportunity observation on 2021 May 11 during its outburst. They found the source to be in the hard-intermediate state, and detected type C quasi-periodic oscillations (QPOs) at the frequencies of 5.4 and 6.3Hz along with a subharmonic at 2.8Hz in the 3-15 keV band. The rms energy spectra indicated the power-law component to be more variable than the disk and reflection components. Based on the X-ray spectroscopy and considering the distance to the source as 8kpc, the estimated mass and spin of the black hole suggested that the source is likely to be a stellar mass Kerr black hole X-ray binary.

Computational Astrophysics

A new turbulence regulated model to estimate impact of relativistic jets on star formation in simulated galaxies

Outflows from supermassive blackholes in galaxies are a major driver of their evolution. It has long been theorised that such energetic jets and winds can regulate the starformation rate in their host galaxy by inducing turbulence in the interstellar medium. However, till date, most theoretical models have considered the density of the gas to be sole criteria to estimate the starformation rate, ignoring any effect of the local velocity dispersion. Scientits at IUCAA have now developed a semi-analytical formalism to estimate quantitatively the impact of the competing effects of jet driven turbulence and shock enhancement of density on the star formation rate in the dense gaseous ISM of galaxies harbouring young jets. The method has been applied to analyse the simulations of jet-ISM interaction carried out earlier in 2018. The method involves identifying contigous

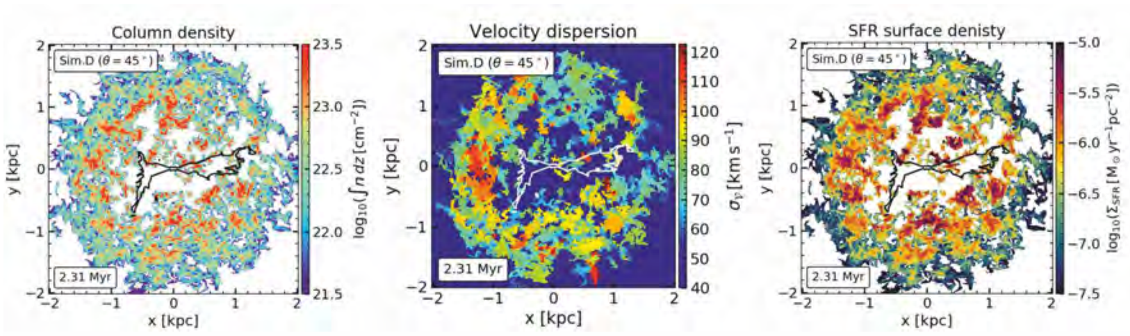


Figure 11: Left: The column density ($\int \rho dz$) in the $X - Y$ plane for one of the simulations. The projected image of the jet tracer is shown in black. Middle: The average mass-weighted velocity dispersion of dense clouds. Right: A map of the mass-weighted starformation rate surface density.

massive clouds and estimating the starformation rate by computing the properties of the internal turbulence of the given cloud. This is a novel approach that ties the well established formalisms followed in domain of turbulence regulated studies starformation in molecular clouds to large scale global simulations of AGN feedback.

The column density map, velocity dispersion and starformation rate surface density for one of the simulations have been presented in Figure 11. **Dipanjan Mukherjee**. **Ankush Mandal**, and collaborators have demonstrated that a jet can both enhance the starformation rate at regions of direct impact and subsequently reduce the efficiency of starformation at other regions where shocks induced by the jet create local turbulence. This is shown in Figure 12, where we present the distribution of starformation rates of clouds as a function of their mean densities. A bi-modal distribution can be seen, where clouds close to the jet have enhanced starformation rate, whereas clouds farther away are lagging compared to the typical values for the no-jet case. This implies that clouds close to the jet have slightly enhanced starformation due to compression from the jet, whereas those at a distance have a lowered efficiency due to increase in velocity dispersion. The work has been led by **Ankush Mandal** as a part of his PhD thesis. The results have been published in the Monthly Notices of the Royal Astronomical Society: **Impact of relativistic jets on the star formation rate: a turbulence-regulated framework**, MNRAS, 508, 4738, 2021.

Estimating the effect of AGN photo-ionisation in radio loud galaxies

Scientist at IUCAA including **Dipanjan Mukherjee** have carried out radiative transfer based compuations to find how radiation from a supermassive blackhole, that also hosts a relativistic jet, can ionise the neighbouring gas in galaxies. The calculations were performed on simulations of jet-ISM interaction carried out earlier in 2018. The effect of collisional ionisation of the ISM due to interactions with the jet and its effect on the photoionisation optical depth was also considered, which has not been done before. It was found that that as jets shock and disturb the gas disks in the galaxy, it significantly changes the structure of the ionisation cones. This is demonstrated in Figure 13 where the extent of regions ionised by the AGN's radiation is shown. Systems with stronger jet-ISM interaction was seen to show enhanced opening of the ionisation cones and increase in the extent of the photionised gas. The results have been published in the Monthly Notices of the Royal Astronomical Society: **The extent of ionization in simulations of radio-loud AGNs impacting kpc gas discs**, MNRAS, 511, 1622, 2021.

Detection of jet induced outflow in NGC 1167

Scientists at IUCAA, including an international team of researchers have detected a low power jet clearing the nuclear region of a galaxy of its gas content. This is the first unambiguous detection of jet driven outflow in such system, where other means of powering such motions can be confidently ruled out. Additionally, since the power of the jet is weaker than the conventional

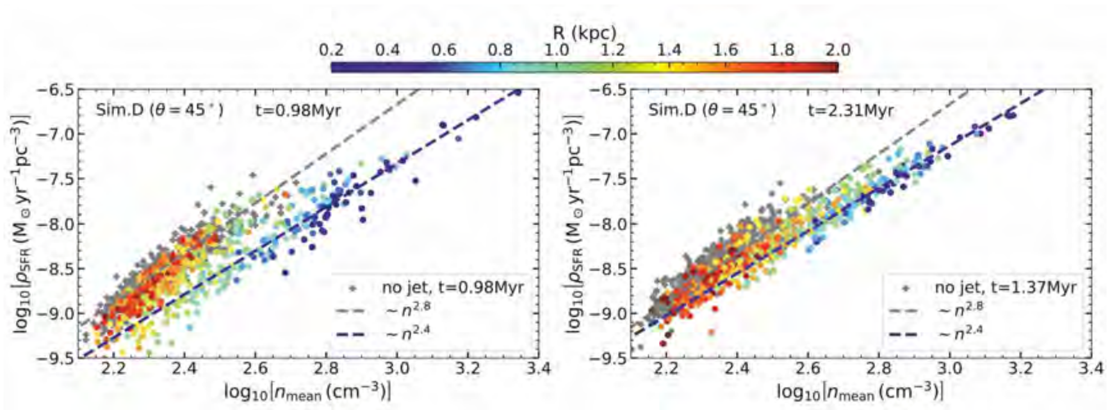


Figure 12: The distribution of starformation rate per unit volume and mean cloud density of different clouds at two different times of a simulation. The grey crosses denote the distribution for a simulation without a jet, serving as a control sample to compare with the jetted simulations. The grey dotted line shows the mean trend for the no-jet case. The clouds for the jetted simulation are represented in colour, with the colorbar indicating the distance from the jet.

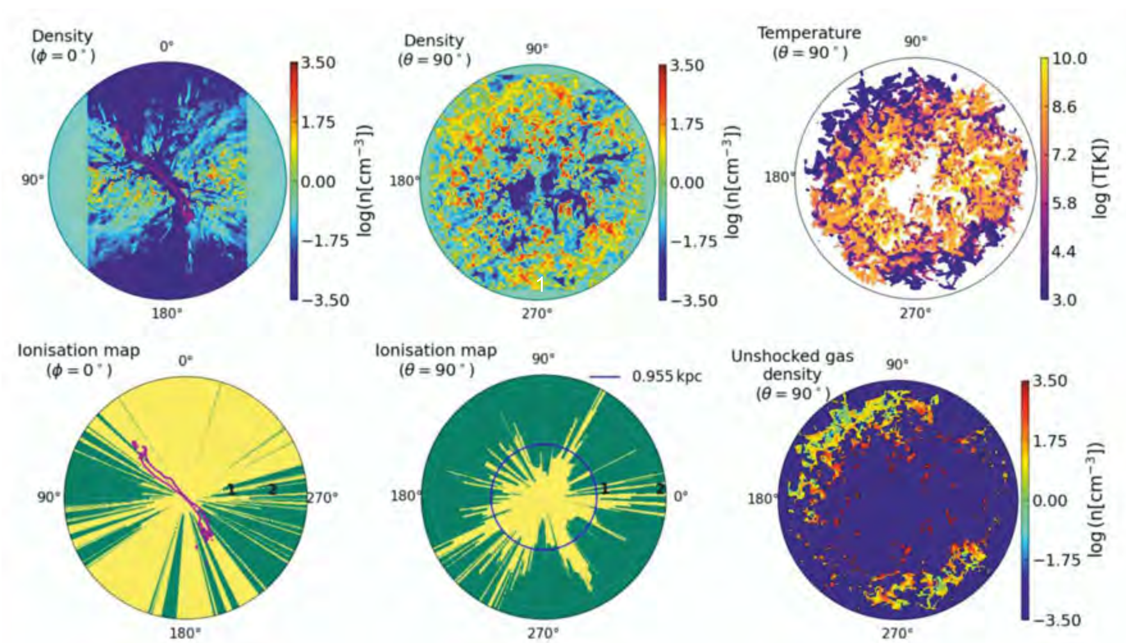


Figure 13: The figures show the cross section of density of a gas disc (view edge on in the top left panel and face on in the middle) being impacted by a relativistic jet. The top right panel shows the temperature of the dense gas ($n > 1$ cm^{-3}). The yellow regions in the bottom left and middle panels (corresponding to edge-on and face-on views respectively) show lines of sight where the AGN's radiation ionises the gas. The blue circle, denostes the mean ionisation radius, which is ~ 1 kpc for this case. The bottom right panel shows the unshocked dense gas that has not been collisionally ionised.

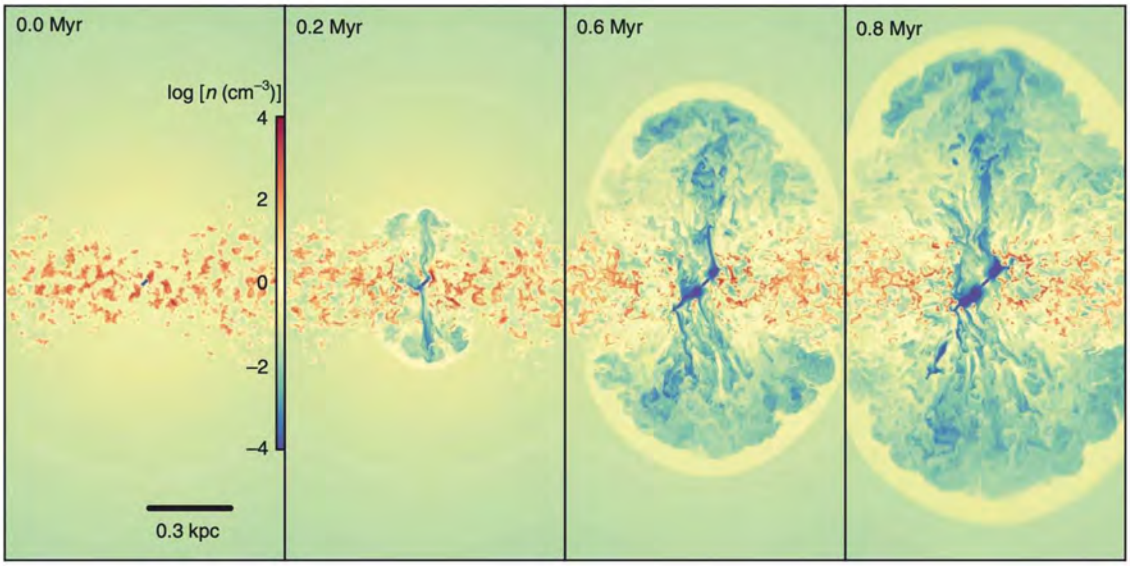


Figure 14: The evolution of density of a gas disk being impacted on by a relativistic jet inclined to it at 45°. The jets are initially impeded in their path, creating large bubble like outflows, before finally breaking out.

jets that are known to cause such outflows, the work firmly establishes that lower power jets can be an important driver of feedback and galaxy evolution. The paper also heavily involves results from simulations performed by in 2018 (see Figure 14), which have been used to qualitatively compare with the observed results. The work has been widely covered in several media outlets and press releases from ASTRON and IUCAA. The result has been recently published in Nature Astronomy: *Cold gas removal from the centre of a galaxy by a low-luminosity jet*, Nature Astronomy, 6, 488, 2022. A snapshot of the simulation performed by me, and used in the paper, has also been featured in the cover page of the April 2022 issue of Nature Astronomy, which is shown in Fig. 14.

Solar Astrophysics

Thermodynamic evolution of a sigmoidal active region with associated flare

Active regions often show S-shaped topology, called Sigmoid in the core of active regions. The S-shaped coronal structures, which are highly sheared and twisted, are observed along the polarity inversion line in the active region and are considered to be one of the best pre-eruption signatures. Fig. 15 shows the sigmoid structure in Fe XVIII map (panel (e)) and X-ray images (panels (g), and (h)) from the X-ray telescope onboard Hinode satellite. Here, Mulay, **Tripathi** and Mason investigate the thermodynamic evolution of an on-disk sigmoid observed during December 24-28, 2015. For this purpose, they have employed Emission Measure (EM) and filter-ratio techniques on the observations recorded by the Atmospheric Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO) and X-ray Telescope (XRT) onboard Hinode. The EM analysis showed multi-thermal plasma along the sigmoid and provided a peak temperature of ∼10-12.5 MK for all observed flares (panels a-d). The sigmoidal structure showed emission from Fe XXI (128.75 Angstorm) lines in the AIA 94 and 131 Angstormchannels (panel (f)). In this work, Mulay, Tripathi and Mason have shown that the hot plasma is often confined to very hot strands within the sigmoidal region. The temperature obtained from the EM analysis was found to be in good agreement with that obtained using the XRT, AIA and GOES filter-ratio methods. These results provide important constraints for the thermodynamic modeling of sigmoidal structures in the core of active regions. Moreover, this study also benchmarks different techniques available for temperature estimation in solar coronal structures.

Hydrodynamics of small transient brightenings in the solar corona

The High Resolution Coronal Imager (HI-C) recorded some of the smallest brightenings in 193 Angstormpass-

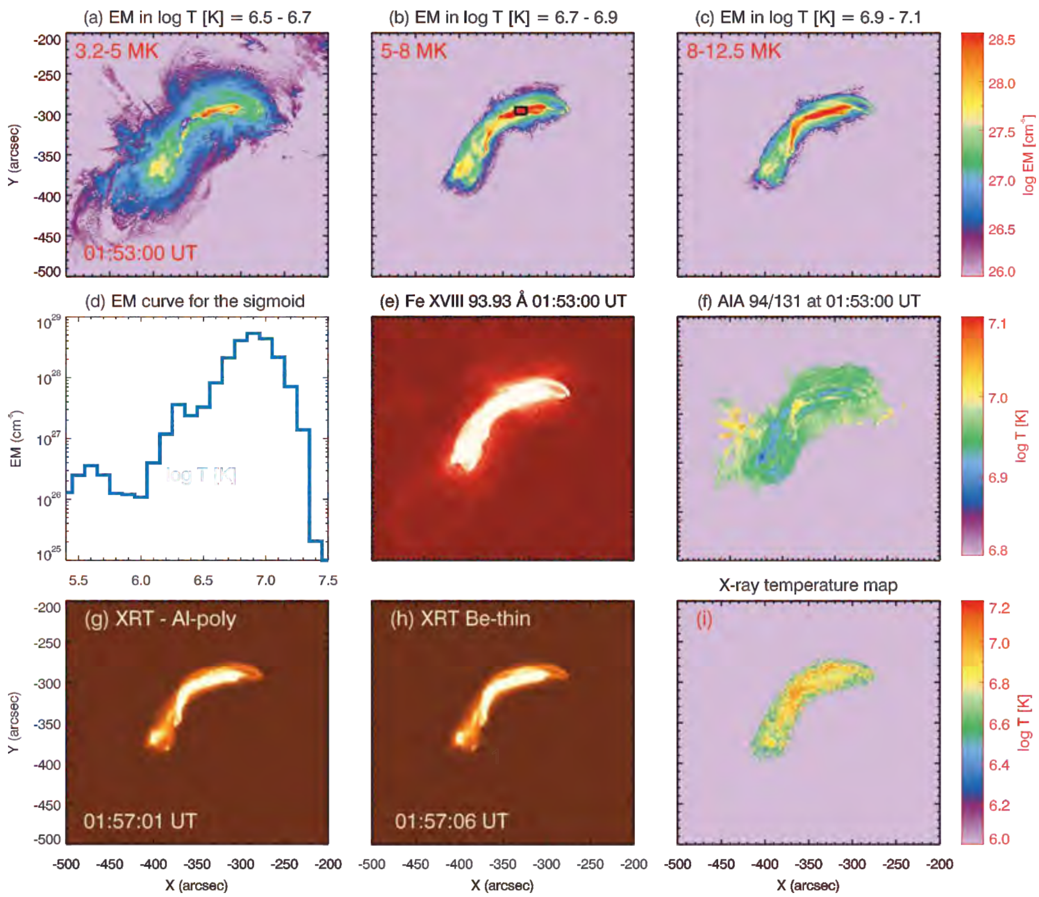


Figure 15: Panel (a-c): Emission measure (EM) maps for sigmoid in various temperature ranges. Panel (d): EM curve obtained for the boxed region in panel (b). Panel (e): Fe XVIII emission derived using the combination of three AIA filters, *viz.* 94, 171 and 211 AngstormPanel (f): Temperature map for the sigmoid obtained using the filter ratio of AIA 94 and 131 channels. Panel (g-h): Sigmoid observed using the X-ray telescope. Panel (i): Temperature map for the sigmoid obtained using the filter ratio of two X-ray channels shown in panel (g) and (h).

band. Using an automatic identification technique, Subramanian, Kashyap and **Tripathi** et al. 2018 identified 27 such brightenings (see Fig. 16) and studied their energetics in detail by employing the differential emission measure technique on the six extreme ultraviolet channels of AIA. They found that the thermal conduction was the dominant cooling mechanism in the corona, a property shared by large flares, microflares and nanoflares. **Rajhans, Tripathi** and Kashyap performed numerical simulations to ascertain if these tiny brightenings can be modeled using same physics as those for larger flares using the Enthalpy Based Thermal Evolution of Loops (EBTEL). For this purpose, a set of input parameters (loop half length, energy budget and duration of heating) were identified to produced synthetic light curves, similar to those recorded by AIA. Simulation results obtained for these input parameters were used for studying the time evolution of conduction, radiation and enthalpy. Rajhans, Tripathi and Kashyap demonstrated that these observations can be modeled using the physics of flares and have a conduction dominated cooling in corona (see Fig. 17) in the early phase. Hence, these results are suggestive of the common underlying mechanism for different classes of flares.

Flows in Enthalpy-Based Thermal Evolution of Loops

1-D simulations of coronal loops show that at a given time, variation of physical quantities like density, pressure and temperature across the loop is small. Hence length averaged physical quantities offer characteristic values for the loops. Studying time evolution of these length averaged physical quantities is the aim of 0-D simulations and offers a significantly faster alternative to 1-D simulations. The Enthalpy Based Thermal Evolution of Loops (EBTEL) is a code based on 0-D hydrodynamical description of coronal loops. However the flow is assumed to be subsonic at all stages. This does not hold good in the impulsive phase and leads to significantly higher velocities than those obtained from 1-D simulations. In some cases it leads to mach numbers exceeding unity, in cases where 1-D simulation predicts subsonic flows. In real world this should lead to shocks creating internal inconsistency. If shocks are indeed produced in field aligned simulations, then velocities produced by 0-D codes should be taken with caution. Therefore it is important to work out a prescription that includes kinetic energy in the energy equation. **Rajhans** and **Tripathi** with colleagues have come up with such a scheme that developed an enhanced version of EBTEL. The enhanced version of EBTEL now allows flows to be in decent agreement with those obtained from field aligned solutions (see Fig. 18). Furthermore enhanced version also fails to predict correct flows in regimes where flows in 1-D field aligned simulations are supersonic. Mach number profiles obtained from 0-D simulations in such cases can be used to get a simple criterion for predicting when the flows in 1-D simulations are supersonic.

On the Impulsive Heating of Quiet Solar Corona

The solar corona is a layer of the atmosphere that hangs far above the "solar surface" or the photosphere. While the photosphere is a ≈6000 K, the solar corona is at more than 1,000,000 K. This counter-intuitive temperature increase in the corona is hypothesized to be caused by extremely small impulsive burst of energies. However, since these events are so small, their presence can be inferred in the corona only statistically. Such statistical analysis requires that we study hundreds of thousands of pixels, and then present the viability & properties of these events. To this end, **Upendran** and **Tripathi** use a statistical, impulsively driven simulation and generate many thousands of template light curves. Next, they develop a deep learning method that learns "how" these light curves may be made. Finally, considering $\geq$ 9,00,000 light curves at different wavelengths, they infer the properties of these impulsive events using the deep learning method. Their algorithm demonstrates that impulsive events are a viable source of coronal heating, and that the properties of these impulsive events follow those of larger impulsive events like flares. **Upendran** and **Tripathi** further find that the results are consistent with the emptying of a background reservoir with small, frequent events or large, intermittent events. Moreover, the properties of these events with temperature, consistent with a cooling dominated by thermal conduction. Thus, a large dataset operated on by empirical impulsive heating model and deep learning inversions generates strong constraints on the coronal heating problem.

Properties of the C II 1334 AngstormLine in Coronal Hole and Quiet Sun

The solar corona is generally differentiated into the dark Coronal Holes (CH), Active Regions (ARs), and the background Quiet Sun (QS). The CHs, well-known sources of the solar wind, are regions that clearly

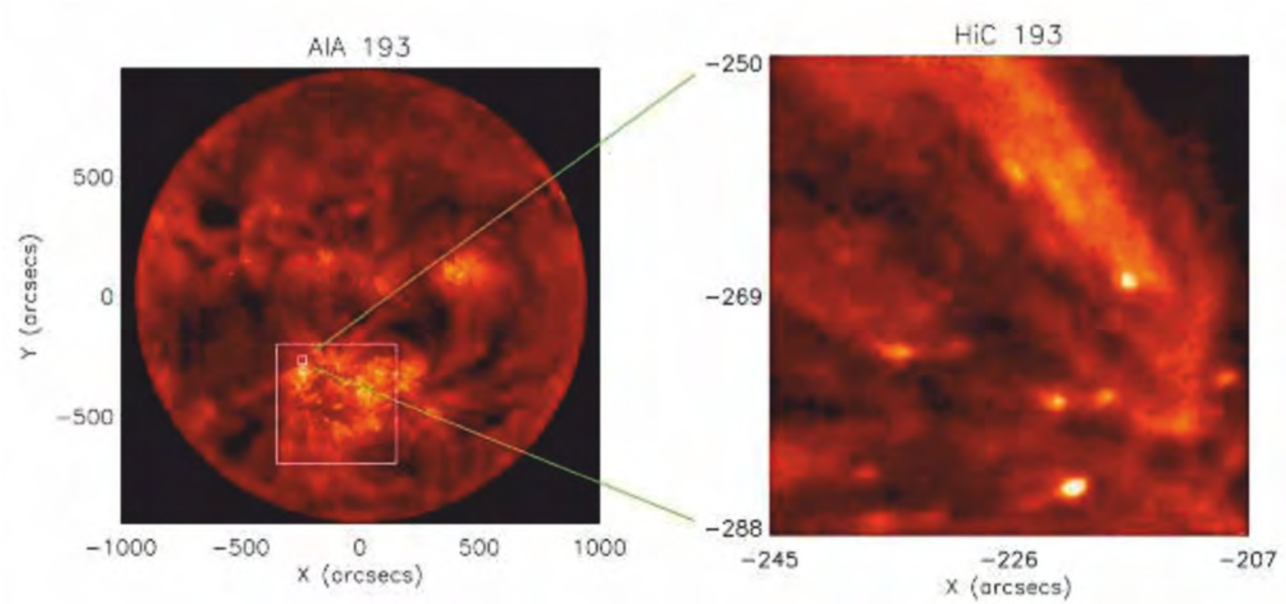


Figure 16: Left: Full disk image of the Sun in AIA-193 passband. The larger white inset represents the Hi-C field of view, whereas the smaller white inset is the region that locates the brightenings studied in detail. Right: Hi-C image corresponding to the smaller white inset in the left panel.

show plasma outflows and reduced intensity when compared to QS in the corona. Here, Upendran and Tripathi study the properties of QS and CHs in the C II 1334 Angstormthat forms a bit lower in the atmosphere called the upper chromosphere. In the C II line, the difference between CHs and QS is not visually seen. These two regions are studied statistically over many regions as a function of the underlying magnetic flux density in the photosphere. Upendran and Tripathi show that while visual differentiation is not present, differences start to arise when the underlying magnetic field is accounted for. Specifically, they find that the outflow signatures in CHs over QS are statistically observed for identical magnetic flux density. Similarly, the intensity is also reduced in CHs over QS for regions with identical magnetic flux density. However, they also find that for pixels which has plasma falling towards the surface, the CHs show a larger velocity over QS. This counter-intuitive result is further validated by the excess asymmetry of the C II line in CHs over QS. These results show the existence of signatures of the solar wind already in the upper chromosphere region. However, it raises further questions on the nature of the dynamics in chromosphere and transition region in CHs.

On the Formation of Solar Wind and Switchbacks, and Quiet Sun Heating

In continuation of the work on the C II line properties in Coronal Holes (CH) and Quiet Sun (QS), **Upendran** and **Tripathi** further study various spectral lines such as Mg II h & k, and Si IV including C II, in tandem. The spectral line properties are studied again as a function of the underlying photospheric magnetic flux density. They find that the chromospheric lines show excess outflows, reduced intensities, and excess inflows in CHs when compared to QS. Since multiple spectral lines and features show this observation, these are clear statistical signatures. However, in the Si IV line only excess outflows and reduced intensities in the CHs when compared to QS was observed. The inflows are stronger in QS for regions with similar magnetic field. This shows a clear dichotomy between the chromosphere and the TR. A cross-correlation analysis suggests that the outflows in the chromosphere are amplified in the TR, while the downflows in the chromosphere may come from either downflows or outflows in the TR hinting towards a mechanism that may be pushing plasma out in opposite directions. Impulsive heating mechanisms are long known to give rise to such plasma response. Hence, these observations support a unified scenario of solar wind emergence and coronal heating. In this scenario, impulsive

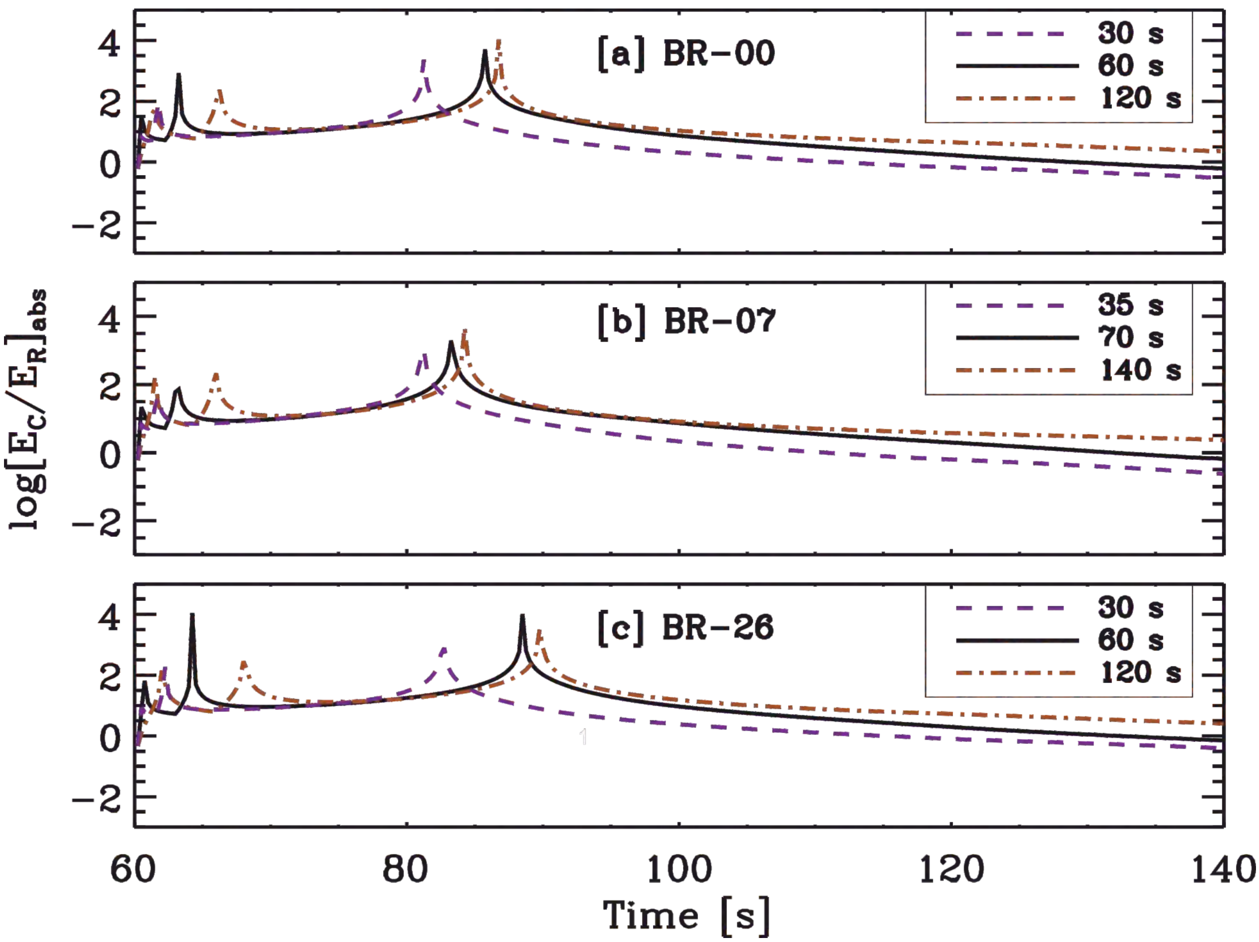


Figure 17: The logarithm of ratio of conduction and radiation loss rates after background subtraction from each. Positive values indicate the dominance of conduction. The result for most suitable duration of heating (black) is bracketed by half (purple) and double (brown) of the value. Results are shown for three individual brightenings *viz.* [a] BR-00, [b] BR-07 and [c] BR-26.

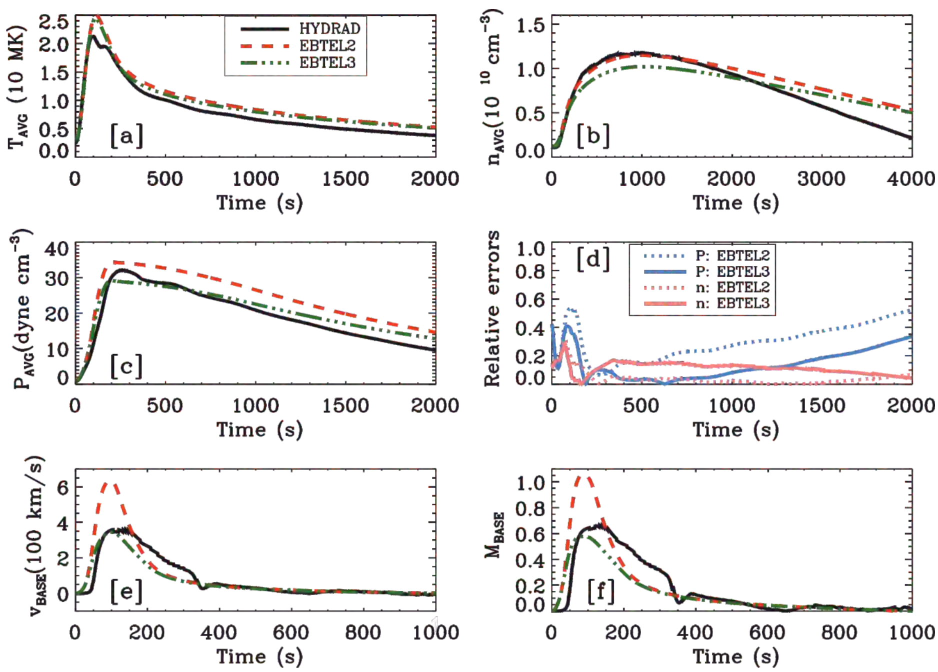


Figure 18: Panel [a]: Average temperature predicted by 1-D (black), original EBTEL (red) and enhanced EBTEL (green) for a case where $3.25\times\ 10^{11}$ ergs cm^{-2} is deposited in 200 s in a loop of half length of 6.5×10^{9} cm. Note that the heating profile is triangular in shape. Panels [b]-[c]: Same as [a] but for average pressure, and average electron number density. Panel [d]: Relative errors in solutions obtained from existing and current versions of EBTEL in density and pressure. Color code is described in inset. Panels [e]-[f]: Same as [a] but for velocity and Mach number at base.

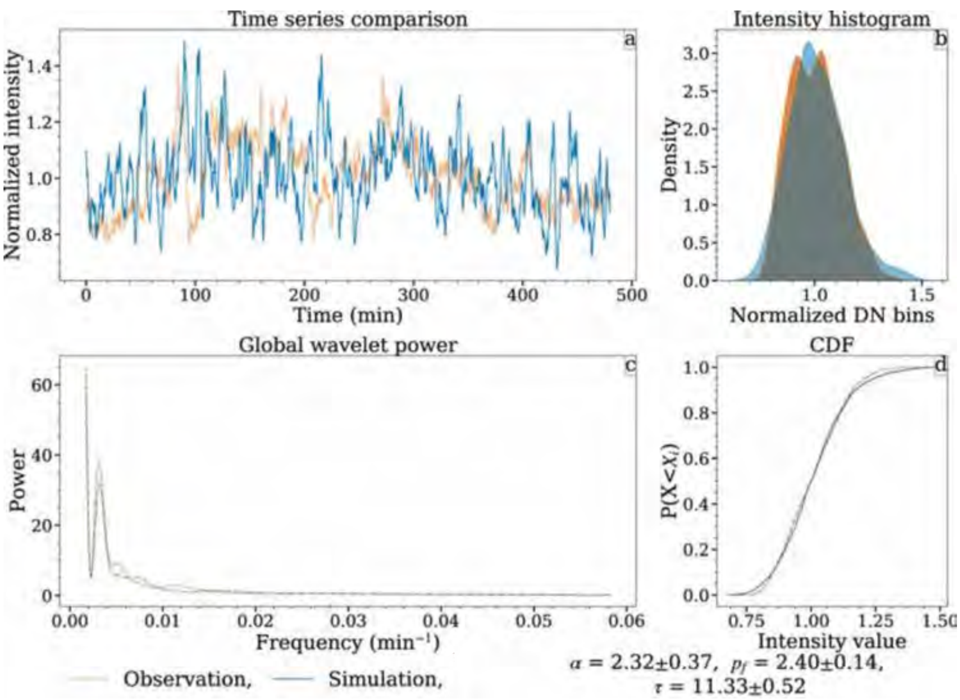


Figure 19: The comparison of a representative light curve obtained for 171 Angstormpassband with a simulated light curve. Observations are shown in translucent orange and simulations are shown in blue. Panel (a): normalized observed and simulated light curves; panel (b): KDE of observed and simulated light curves; panel (c): global Morlét wavelet power for observation and simulations; and panel (d): CDF comparison of simulation and observation.

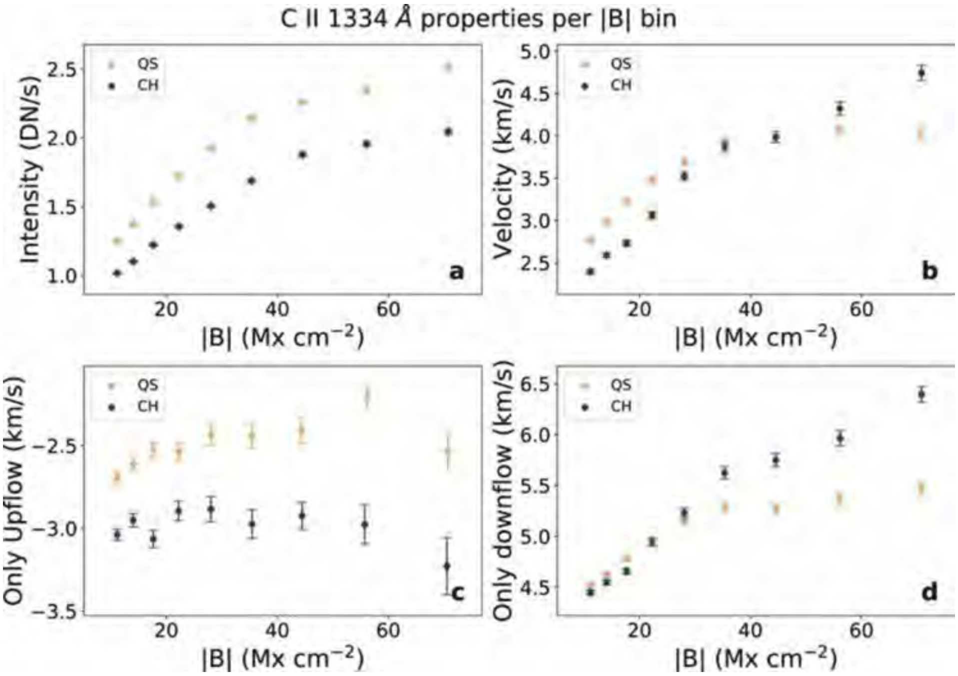


Figure 20: Variation of C II 1334 Angstormproperties with absolute magnetic flux density. We show the intensity in panel (a) and the average velocity in panel (b). In panel (c), only pixels with upflows have been considered, while in panel (d) only pixels with downflows have been considered. The color scale once again follows black for CHs and orange for QS.

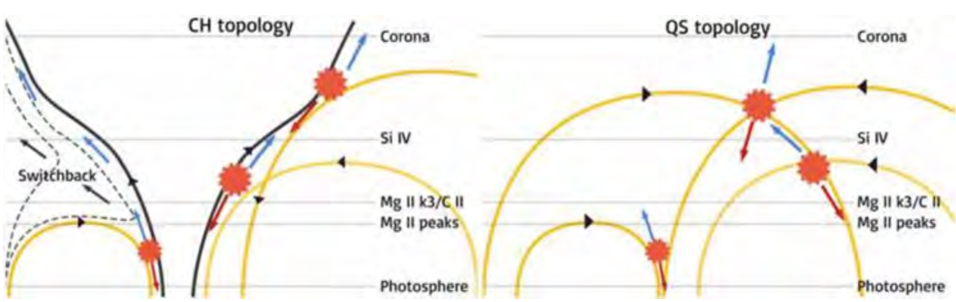


Figure 21: A schematic depicting the proposed picture of impulsive heating occurring across different magnetic field topologies. In the left panel, we show a CH topology, including an open funnel-like structure (black) and closed loops of varying sizes (yellow). Impulsive events (red asterisks) due to interchange reconnection between the open and closed field lines give rise to bidirectional flows (blue and red arrows). Of these flows, the upflows are enhanced due to density stratification and the expanding flux tube in CHs. Interchange reconnection may occur over a range of heights, and the corresponding bidirectional flows may be observed across different spectral lines marked in approximate order of formation height. An example of the reconnected field line propagating outward as a switchback is depicted as the dashed line, with the approximate propagation direction depicted by the black arrows. Right panel: QS topology depicted with the same terminology as CH topology. Note here that while one does expect correlated bidirectional flows in QS, the upflows are not accelerated due to the absence of funnel-like structures.

heating in CHs occurs due to interchange reconnection, while in QS occurs due to closed loop reconnection. The plasma response to reconnection at different heights can give rise to different kinds of flows. Finally, the kinked field lines may also travel outwards as rotations in the magnetic field, called switchbacks.

Quantum Technologies

Precision & Quantum Measurement laboratory (PQM-lab: https://pqmlab.iucaa.in/) Present team members Sankalpa Banerjee (research fellow), Isita Chatterjee (research fellow), Prabhat Manna (research fellow), Stanley Johnson (research associate), Sujaya Das Gupta (research associate), and Subhadeep De (project investigator)

The research activities of Precision & Quantum Measurement laboratory (photograph of the labis shown in Fig. 1) are focused on:(i) quantum metrology, (ii) precision measurements, and (iii) developing quantum-phenomena based sensors/ technologies. The heart of the experimental setup is a trappedytterbium-ion-based quantum clock. For this, a single ytterbium-ion will be trapped in an indigenously developed precision ion trap and the ion will be cooled to sub-mK temperature using the laser cooling technique. The laser-cooled and confined ytterbium-ion will then be used to probe its highly forbidden electric octupole (E3) clock transition at 642 121 496 772 645.15 Hz, with few tens of mHz accuracy. For exciting the clock transition, an ultra-stable laser having sub-Hz line-width at 467 nm wavelength will be required. This will be produced by referencing a commercial laser to an indigenously developed reference optical resonator (Fabry-Prot cavity). Tomake the PQM-lab experiment useful, the ultra-stable nearly monochromatic photons needs to be disseminated to geographically distributed locations within the country and outside for establishing networks of optical clocks and intercomparison. For that, we will use lasers atcommunication wavelength-1550 nm and transport them using optical fibers. However, this is different than the standard optical communication as the photons frequency and phase themselves need to be specific and ultra-stable (narrow line-width as well as having long-term stability in their phase and frequency) over this long or very-long distance of transportation. To meet the requirement aforementioned, activephase noise cancellation of the optical fiber by stabilizing its length will be implemented , which is a critical technology under development at the PQM-lab. For absolute referencing of the communication laser at 1550 nm wavelength, it will be referenced to the optical clock through an intermediate optical frequency comb. The arrangement of the optical clock, reference cavity, communication laser, and stabilized fiber link are schematically shown in Fig. 2, and the present development status of these building blocks is described in the following sections.

To develop the complex experiment, the main challenge is that the optical atomic clock and its associated technologies need to be indigenized. For that, we need to bring together expertise in the field of laser & optics, instrumentation, electronics, and ultra-high vacuum, mechanical and software engineers, all of them have to work collaborativelywith physicists as the experiment has to be customized to fulfill the particular science goals.In the long term, PQM-lab plans to work on three major inter-connecting areas, which are:

(i) establishing a lab-based reference optical clock, (ii) ultra-stable optical links to network among distant optical clocks, and (iii) developing a chip ion-trap.

The heart of our PQM-labs experiment is the trapped ion optical atomic clock. Even though the instrument is named clock, it measures the frequency of the E3-clock transition at 642 121 496 772 645.15 Hz, with an unprecedented accuracy of a few tens of mHz. Ions are freely moving particles due to their residual kinetic energies, hence their probability of interacting with laser light traveling along a fixed direction is a bare minimum. Thus, the creation of a highly controlled environment where the experimenting ion(s) can be confined and where all the other parameters, such as stray electric and magnetic fields,are either cancelled or accurately quantified, is necessary for such highly accurate measurements. To achieve this,the ions are confined using oscillating electric fields in a Paul trap. Though trapped, the ions are still energetic,which is reduced to a sub-mK temperature by laser cooling. This is100 000 times lower than the room temperature. Upon producing the cold sample confined in their respective traps, the clock transition is excited using light from an ultra-stable and narrow line-width laser, and the occurrence of the excitation is ensured by the detection of the fluorescence produced in this process. Production of sub-Hz line-width laser is another state-of-the-art technology, which uses an ultra-stable reference optical resonator, namely a Fabry-Prot(FP) cavity. Essentially, the stability of this external optical resonator is imprinted on the laser and only a certain optical frequency sustains while oscillating round-trip inside the FP-cavity. Thus, it acts as a narrow band-pass optical filter together with the reduction of the phase noise, resultingin narrowing down a 200 times reduction in the laser frequency noise when the PID controller is on i.e. when frequency locking is active.We are working to further reduce the locking noise by carefully identifying and removing timing violations in the FPGA design, and by using lower noise power supplies. With further modifications, we plan to use the PID design to cancel the Doppler frequency shift induced by light passing over optical fiber, enabling the dissemination of optical clock signals over long distances.

To develop the complex experiment, the main challenge is that the optical atomic clock and its associated technologies need to be indigenized. For that, we need to bring together expertise in the field of laser & optics, instrumentation, electronics, and ultra-high vacuum, mechanical and software engineers, all of them have to work collaborativelywith physicists as the experiment has to be customized to fulfill the particular science goals.In the long term, PQM-lab plans to work on three major inter-connecting areas, which are: (i) establishing a lab-based reference optical clock, (ii) ultra-stable optical links to network among distant optical clocks, and (iii) developing a chip ion-trap. The heart of our PQM-labs experiment is the trapped ion optical atomic clock. Even though the instrument is named clock, it measures the frequency of the E3-clock transition at 642 121 496 772 645.15 Hz, with an unprecedented accuracy of a few tens of mHz. 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The frequency comb outputs an array of equally spaced discrete optical frequencies over a wide band, and the particular frequency of the laser that probes the clock transition is locked in phase to oneof the optical combs outputs frequencies. This phase locks all the discrete output frequencies of the optical comb and enables optical frequencies far away from the clock transition frequency to be phase and frequency locked to the clock transition. This is auseful tool to bridge the gap between clock transition and fiber optic telecommunication frequencies, also used for ultrastable microwave generation by intercomparing its stabilized discrete optical frequencies. In the time domain, the frequency comb locked to an optical clock transition produces periodic optical pulses with the same ultra-low uncertainty of the clock transition.Upon generation of the ultra-stable reference optical frequency using an optical atomic clock and its associated technologies, for all practical purposes, such as long-term frequency comparison between different optical atomic clocks for studying fundamental science,providingtraceability of the reference optical frequencies to a remote location; dissemination of these reference photons to a distant location is necessary. Normal optical fiber communication does not work for this, sinceit involves complex technology to stabilize the length of a long optical fiber to an atomic length scale. This is called phase stabilization of the optical fiber for dissemination of the reference optical photons without losing its phase information and introducing noise to it. The PQM-lab, to start with, is focused on developing a precision ion-trap, ultrastable FP-cavity, and phase stabilization of the optical fiber. We shall briefly describe progress on these in the sections below. (a)Science chamber: An ion-trap with end-cap geometry will be employed in our experiment to confine a single ion in a nearly pure quadrupole potential created by it. For this, elaborate simulations have been performed to identify the most suitable geometric parameter, choices of the material, and thereby minimum systematics induced by the trap itself. Precision machining of the ion trap and custom design of its ultra-high vacuum (UHV)container, as shown in Fig. 3, are required to meet the experimental requirement. The compact science chamber design

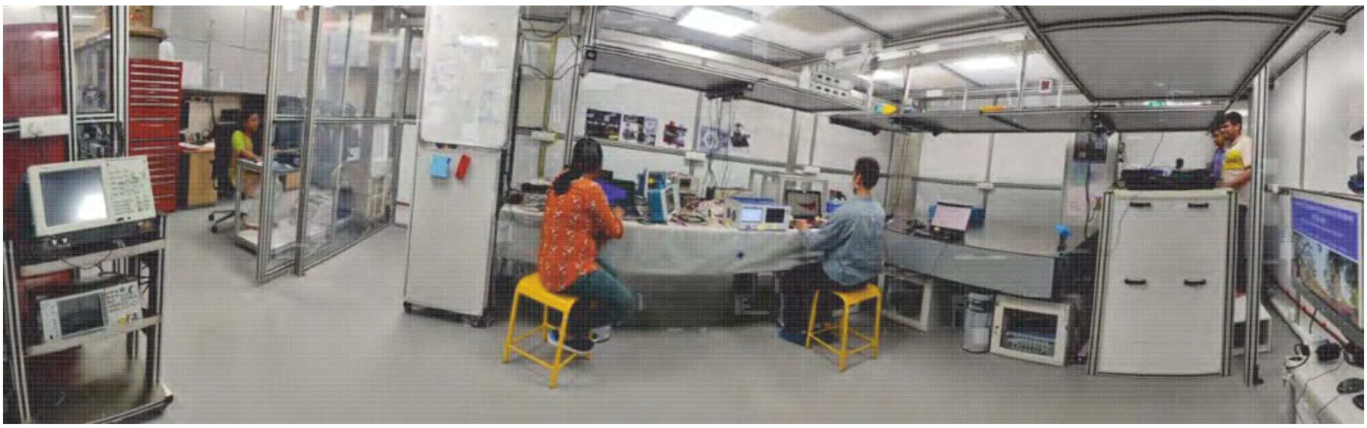


Figure 22: Figure 1: The Precision & Quantum Measurement laboratory (PQM-lab), since June 2021 at IUCAA. The research activities of Precision & Quantum Measurement laboratory (photograph of the labis shown in Fig. 1) are focused on:(i) quantum metrology, (ii) precision measurements, and (iii) developing quantum-phenomena based sensors/ technologies. The heart of the experimental setup is a trappedytterbium-ion-based quantum clock. For this, a single ytterbium-ion will be trapped in an indigenously developed precision ion trap and the ion will be cooled to sub-mK temperature using the laser cooling technique. The laser-cooled and confined ytterbium-ion will then be used to probe its highly forbidden electric octupole (E3) clock transition at 642 121 496 772 645.15 Hz, with few tens of mHz accuracy. For exciting the clock transition, an ultra-stable laser having sub-Hz line-width at 467 nm wavelength will be required. This will be produced by referencing a commercial laser to an indigenously developed reference optical resonator (Fabry-Prot cavity). Tomake the PQM-lab experiment useful, the ultra-stable nearly monochromatic photons needs to be disseminated to geographically distributed locations within the country and outside for establishing networks of optical clocks and intercomparison. For that, we will use lasers atcommunication wavelength-1550 nm and transport them using optical fibers. However, this is different than the standard optical communication as the photons frequency and phase themselves need to be specific and ultra-stable (narrow line-width as well as having long-term stability in their phase and frequency) over this long or very-long distance of transportation. To meet the requirement aforementioned, activephase noise cancellation of the optical fiber by stabilizing its length will be implemented , which is a critical technology under development at the PQM-lab. For absolute referencing of the communication laser at 1550 nm wavelength, it will be referenced to the optical clock through an intermediate optical frequency comb. The arrangement of the optical clock, reference cavity, communication laser, and stabilized fiber link are schematically shown in Fig. 2, and the present development status of these building blocks is described in the following sections.

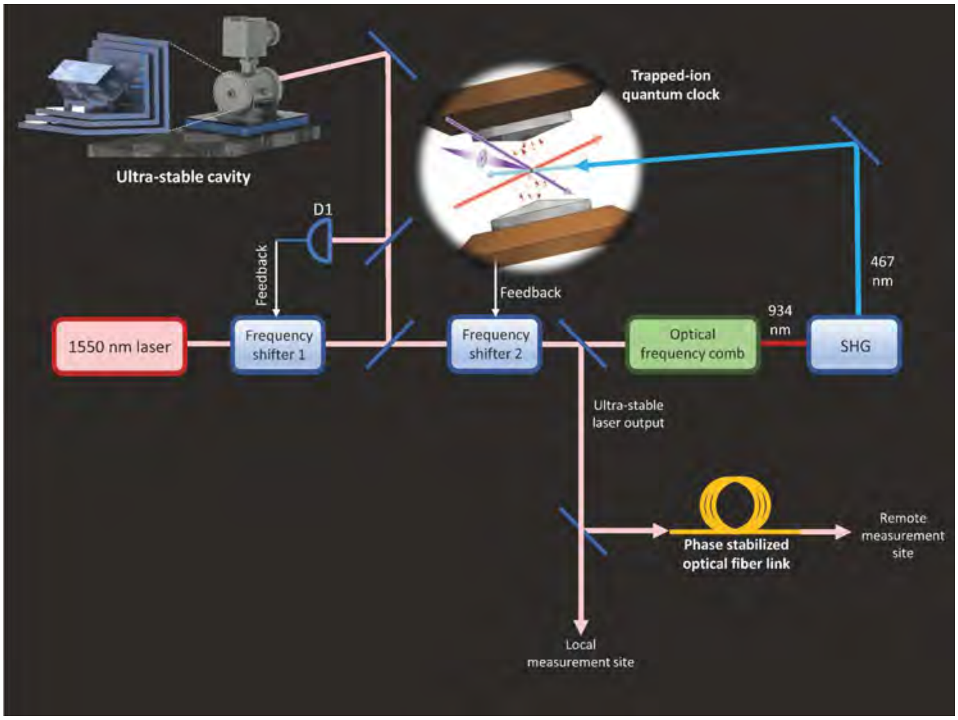


Figure 23: Schematic of the experimental setup that consists of three major sophisticated technologies: ytterbium-ion-based optical clock, generation of sub-Hz linewidth & ultrastable laser, and phase stabilization of optical fiber.

contains the trap, ytterbium atomic oven, helical resonator, single-ion imaging system, and magnetic coils in all three directions.The precision ion trap development satisfying the critical design parameters is being carried out in collaboration with the team led by Sadiq Rangawala at RRI Bangalore to meet the requisites from both our research groups and possibly to a wider community in the country.

(b) Reference optical resonator: A Fabry-Perot (FP) cavity consists of two highly reflective mirrors separated by a robust spacer, which acts as an optical resonator since ideally, only certain identical photons sustain after multiple round trips (∼105) within it. Upon building an ultra-stable FP cavity, its length stability can be transferred to another laser to lock its frequency using Pound-Drever-Hall (PDH) technique. This we are implementing to produce an ultra-narrow linewidth (sub-Hz) & ultra-stable (∼10-16 at 1 s) laser, which will be used to probe the clock transition.

The reference FP-cavity is a state-of-the-art technology that we are indigenizing at our lab. We have studied every aspect of instabilities affecting the FP cavity such as the effect of optical higher-order modes (HOMs), deformation due to self-weight, temperature change, seismic vibration, thermal noise, etc. The analysis work has been carried out in collaboration with the team of Sandip Haldar at IIT Goa. Upon analyzing different material properties, we decided to use Ultra-Low Expansion (ULE) glass as spacer material and fused silica for the mirror. The entire assembly will be inside of a UHV, as shown in Fig. 4. Simulation obtains fractional frequency instability of $\sigma y = 2.810 - 16$ over an integration time of 1 s for our optimized FP-cavity and that is compared with the internationally reported other such cavities in Fig. 5.

(c) Development of low-noise laser locking electronic hardware: We have created a very low noise FPGA-based electronic hardware that will be used for PDH locking of the laser with respect to the ultrastable FP-cavity. To test the performance of the developed locking hardware, we developed an FPGA based emulator that includes the laser, reference cavity,and the detector, which is used to generate an analog signal for the FPGA-based proportional-integral-derivative (PID) controller and fed its output to the emulator for locking of the emulated randomized laser frequency. For the locking hardware itself, we use two FPGA boards, both clocked from a singlerubidium clock. They are connected to the

the line-width of the laser. The ultra-stable optical resonator acts as the flywheel oscillator of the absolute optical reference that comes from very accurate probing of the clock transition.Another important tool the optical frequency comb, is used to make the optical clock transition frequency countable. The frequency comb outputs an array of equally spaced discrete optical frequencies over a wide band, and the particular frequency of the laser that probes the clock transition is locked in phase to oneof the optical combs outputs frequencies. This phase locks all the discrete output frequencies of the optical comb and enables optical frequencies far away from the clock transition frequency to be phase and frequency locked to the clock transition. This is auseful tool to bridge the gap between clock transition and fiber optic telecommunication frequencies, also used for ultra-stable microwave generation by intercomparing its stabilized discrete optical frequencies. In the time domain, the frequency comb locked to an optical clock transition produces periodic optical pulses with the same ultra-low uncertainty of the clock transition. Upon generation of the ultra-stable reference optical frequency using an optical atomic clock and its associated technologies, for all practical purposes, such as long-term frequency comparison between different optical atomic clocks for studying fundamental science,providingtraceability of the reference optical frequencies to a remote location; dissemination of these reference photons to a distant location is necessary. Normal optical fiber communication does not work for this, sinceit involves complex technology to stabilize the length of a long optical fiber to an atomic length scale. This is called phase stabilization of the optical fiber for dissemination of the reference optical photons without losing its phase information and introducing noise to it. The PQM-lab, to start with, is focused on developing a precision ion-trap, ultrastable FP-cavity, and phase stabilization of the optical fiber. We shall briefly describe progress on these in the sections below.

(a)**Science chamber:**

An ion-trap with end-cap geometry will be employed in our experiment to confine a single ion in a nearly pure quadrupole potential created by it. For this, elaborate simulations have been performed to identify the most suitable geometric parameter, choices of the material, and thereby minimum systematics induced by the trap itself. Precision machining of the ion trap and custom design of its ultra-high vacuum (UHV)container, as shown in Fig. 3, are required to meet the experimental requirement. The compact science chamber design contains the trap, ytterbium atomic oven, helical resonator, single-ion imaging system, and magnetic coils in all three directions.The precision ion trap development satisfying the critical design parameters is being carried out in collaboration with the team led by Sadiq Rangawala at RRI Bangalore to meet the requisites from both our research groups and possibly to a wider community in the country.

(b) **Reference optical resonator:**

A Fabry-Prot (FP) cavity consists of two highly reflective mirrors separated by a robust spacer, which acts as an optical resonator since ideally, only certain identical photons sustain after multiple round trips (105) within it. Upon building an ultra-stable FP cavity, its length stability can be transferred to another laser to lock its frequency using Pound-Drever-Hall (PDH) technique. This we are implementing to produce an ultra-narrow linewidth (sub-Hz) & ultra-stable ($\sim$ 10-16 at 1 s) laser, which will be used to probe the clock transition. The reference FP-cavity is a state-of-the-art technology that we are indigenizing at our lab. We have studied every aspect of instabilities affecting the FP cavity such as the effect of optical higher-order modes (HOMs), deformation due to self-weight, temperature change, seismic vibration, thermal noise, etc. The analysis work has been carried out in collaboration with the team of Sandip Haldar at IIT Goa. Upon analyzing different material properties, we decided to use Ultra-Low Expansion (ULE) glass as spacer material and fused silica for the mirror. The entire assembly will be inside of a UHV, as shown in Fig. 4. Simulation obtains fractional frequency instability of y= 2.810-16 over an integration time of 1 s for our optimized FP-cavity and that is compared with the internationally reported other such cavities in Fig. 5.

(c) **Development of low-noise laser locking electronic hardware:**

We have created a very low noise FPGA-based electronic hardware that will be used for PDH locking of the laser with respect to the ultrastable FP-cavity. To test the performance of the developed locking hardware, we developed an FPGA based emulator that includes the laser, reference cavity,and the detector, which is used to generate an analog signal for the FPGA-based proportional-integral-derivative (PID) controller and fed its output to the emulator for locking of the emulated randomized laser frequency.

For the locking hardware itself, we use two FPGA boards, both clocked from a singlerubidium clock. They are connected to the PDH emulator, in the same manner one would connect to an actual PDH setup, as shown in Fig. 6. Using this emulator, we have demonstrated

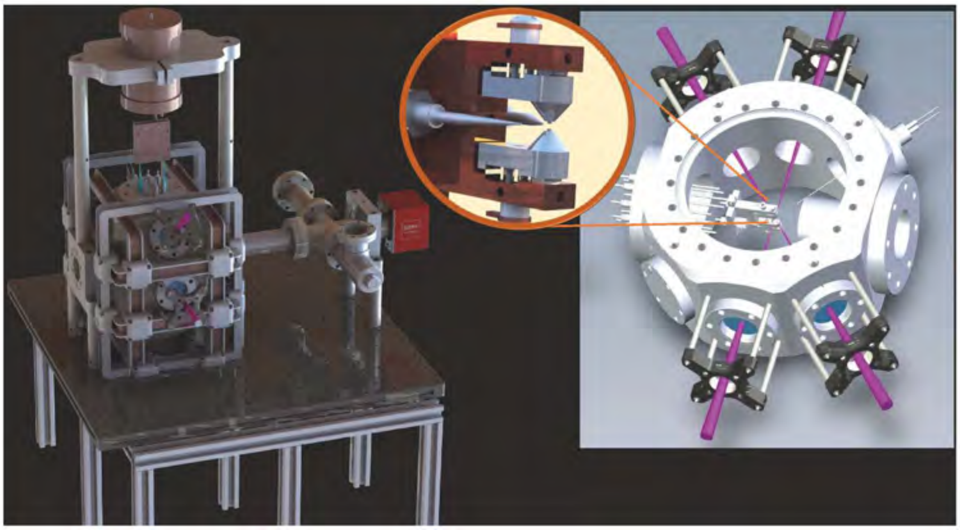


Figure 24: The design of the science chamber that consists of the ultra-high vacuum container, magnetic coils along all three directions, helical resonator, and high-resolution imaging system.

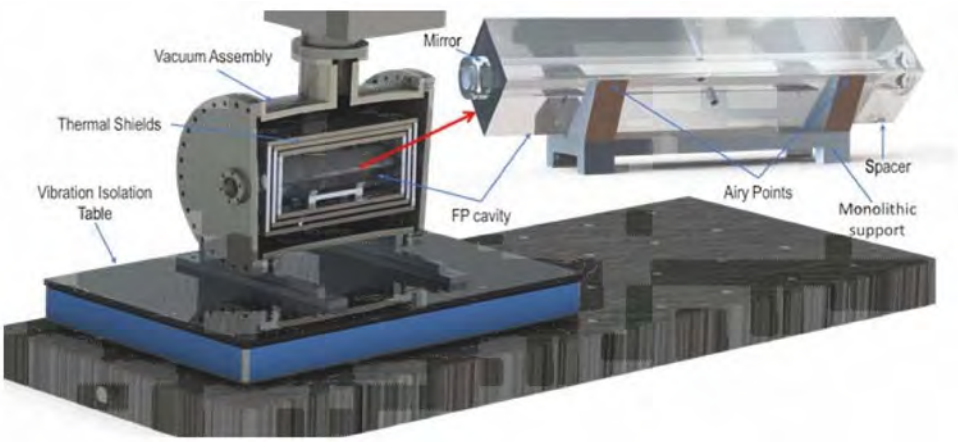


Figure 25: Fabry-ProtCavity is housed in an ultra-high vacuum chamber and three layers of thermal shields. The entire assembly is placed on an active vibration isolation table.

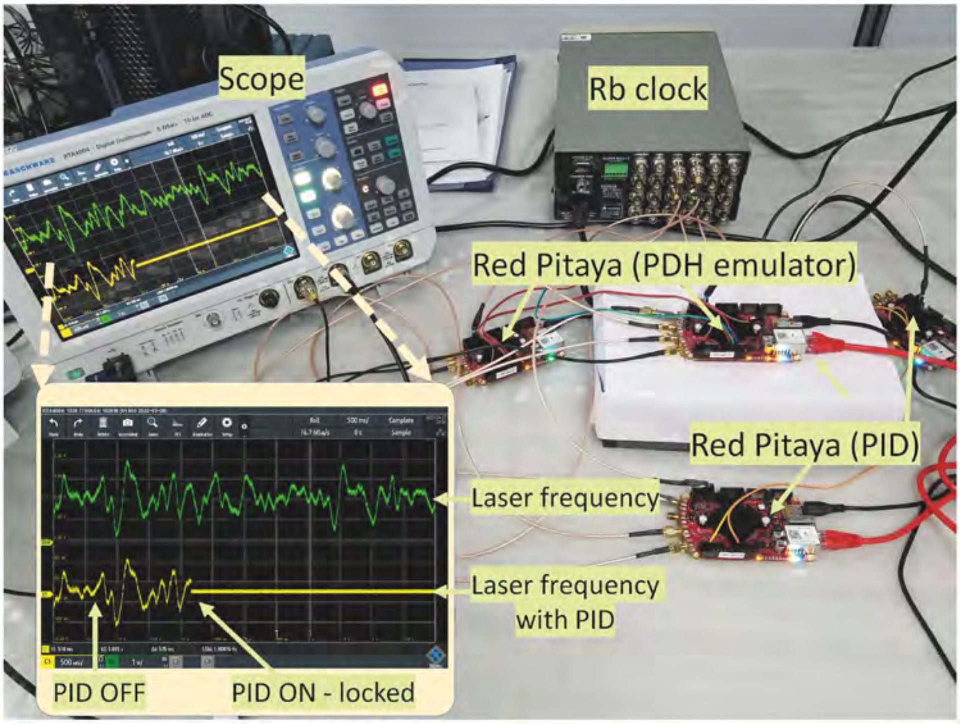


Figure 27: Experiment setup demonstrating the emulated locking of a laser to an ultra-stable cavity using an FPGA-based PID controller. Note the steady/locked laser frequency when the PID is turned on, in the inset.

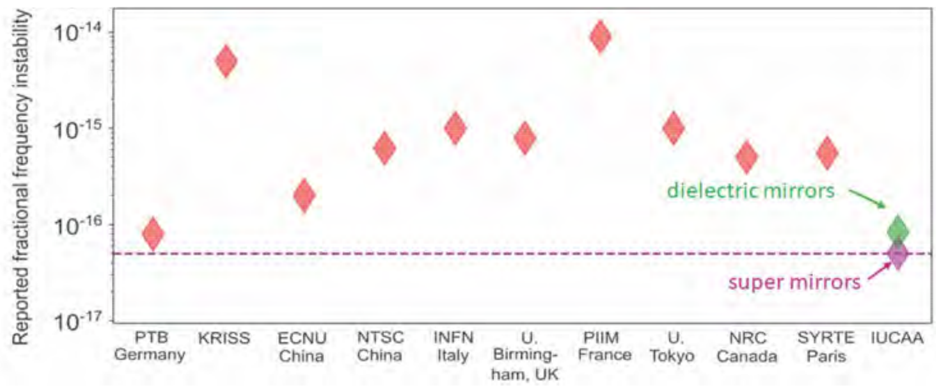


Figure 26: Reported stabilities of the FP cavities around the world at room temperature (red), cryogenic (blue) ,and that is compared to our result (green).

PDH emulator, in the same manner one would connect to an actual PDH setup, as shown in Fig. 6. Using this emulator, we have demonstrated a 200 times reduction in the laser frequency noise when the PID controller is on i.e. when frequency locking is active.We are working to further reduce the locking noise by carefully identifying and removing timing violations in the FPGA design, and by using lower noise power supplies. With further modifications, we plan to use the PID design to cancel the Doppler frequency shift induced by light passing over optical fiber, enabling the dissemination of optical clock signals over long distances.

PEDAGOGICAL

(a) IUCAA – NCRA Graduate School

Dipankar Bhattacharya (IUCAA)

Methods of Mathematical Physics 1 (14 lectures) (25 Oct – 17 Dec 2021)

Sukanta Bose (IUCAA)

Methods of mathematical physics II(14 lectures)(27 Dec 2021 – 26 Feb 2022)

Debarati Chatterjee (IUCAA)
Quantum and statistical mechanics semester I Term II (14 lectures) (5 Jan - 23 Feb 2022)

Ranjeev Misra (IUCAA)

Electrodynamics and radiative processes II (14 lectures) (27 Dec 2021 – 26 Feb 2022)

Dipanjan Mukherjee (IUCAA)

Electrodynamics and radiative processes I(14 lectures)(25 Oct – 17 Dec 2021)

Somak Raychaudhury (IUCAA)

Introduction to Astronomy and Astrophysics I (14 lectures)(25 Oct – 17 Dec 2021)

Durgesh Tripathi (IUCAA)

Introduction to astronomy and astrophysics II (14 lectures) (27 Dec 2021 – 26 Feb 2022)

(b) SAVITRIBAI PHULE PUNE UNIVERSITY MSc LECTURES

(Departments of Physics, and Department of Space Science)

Neeraj Gupta

Radio Astronomy (Theory 4 lectures), and supervision of radio astronomy experiments)

Ranjan Gupta

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

Surhud More

Astronomy and Astrophysics II, Cosmology

D. J. Saikia

Astronomy and Astrophysics – I, Introductory Astronomy and Astrophysics (40 lectures delivered online) (October 2021 – January 2022)

Nishant Singh

Astronomy and Astrophysics – II, General Relativity

(c) SAVITRIBAI PHULE PUNE UNIVERSITY BSc LECTURES

Kandaswamy Subramanian

Interdisciplinary School of Science, Introduction to Astrophysics (27 lectures) (August to November 2021) (Online)

(c) SUPERVISION OF PhD THESES

(Degrees Awarded)

Aseem Paranjape

Title: *Halo Dynamics and Kinematics: Applications to Large Scale Structure and Cosmology.*
Student: Sujatha Ramakrishnan(IUCAA)

Varun Sahni

Title: *Dark Matter, Dark Energy and the Early Universe.*
Student: SwagatMisra (IUCAA)

(d) SUPERVISION OF PhD THESES

(Degrees ongoing - IUCAA)

Dipankar Bhattacharya

Title: *An investigation of polarized emission from Accreting Binary X-ray Pulsars.*
Student: PariseeShirke (IUCAA)

Sukanta Bose and Anupreeta More

Title: *Using Gravitational Waves from Compact Binary Coalescences to Probe Gravitational Lensing (Strong and Micro) And The Magnetic Penrose Process.*
Student: Anuj Mishra (IUCAA)

Debarati Chatterjee

Title: *Study of the role of neutron star composition on gravitational wave emission.*
Student: Bikram K. Pradhan (IUCAA)

Title:*Study of the role of transport properties in neutron stars on gravitational wave emission.*
Student: Suprovo Ghosh (IUCAA)

Title: *Hadron-quark phase transition in Neutron Stars in the light of recent multi-messenger observations.*
Student: SwarnimShirke (IUCAA)

Gulab Dewangan

Title: *Soft X-ray Excess and Accretion Disk/Corona Emission from Active Galactic Nuclei.*
Student: Prakash Tripathi (IUCAA)

Title: *AstroSat view of accretion discs in Active Galactic Nuclei.*
Student: Shrabani Kumar (IUCAA)

Title: *Accretion disk-corona interplay in Active Galactic Nuclei*
Student: KavitaKumari(IUCAA)

Title: Active Galactic Nuclei and Bright UV Sources in the AstroSat/UVIT Field
Student: PiyaliGanguli(IUCAA)

Neeraj Gupta

Title: *An unbiased view of cold atomic gas associated with radio-loud AGNs.*
Student: ParthaPratimDeka(IUCAA)

SanjitMitra

Title: *Algorithms for Gravitational Wave Data Analysis and Detector Controls Based on Modern Techniques.*
Student: ShreejitJadhav(IUCAA)

Title: *Methods and Scientific Potentials of Stochastic Gravitational Wave Background Analyses.*
Student: Deepali Agarwal(IUCAA)

Title: *Efficient Searches for Compact Binary Coalescences and Science in the LIGO-India Era.*
Student: KanchanSoni(IUCAA)

Surhud More

Title: *The Galaxy Dark Matter Connection.*
Student: NavinChaurasiya (IUCAA)

Title: *Cosmology from Galaxy Clusters3.*
Student: Amit Kumar (IUCAA)

Title: *Gravitational Lensing in Galaxy Clusters.*
Student: Divya Rana (IUCAA).

Title: *Gravitational Lensing probes of Dark Matter.*
Student: Priyanka Gawade(IUCAA)

Dipanjan Mukherjee

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

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

Aseem Paranjape

Title: *Exploring the Nature of Dark Matter using Astrophysical and Cosmological Probes.*
Student: Bhaskar Arya (IUCAA)

Title: *Interplay of galaxy formation and the evolution of dark matter haloes in the cosmic web.*
Student: Mr. PremvijayVelmani (IUCAA)

Kanak Saha

Title: *Probing the ionizing radia/on of high-redshi3 galaxies using AstroSat.*
Student:SoumilMaulick(IUCAA)

Title: *Probing the assembly of galaxies in high-z universe.*
Student:Manish Kataria (IUCAA)

Title: *Clump dynamics of Star-forming galaxies at intermediate redshift.*
Student: Pushpak Pandey(IUCAA)

Nishant Singh

Title: *Aspects of Turbulent Convection: Implications for Solar Differential Rotation and Small-Scale Dynamos.*
Student: Kishore Gopalakrishnan (IUCAA)

(e) SUPERVISION OF PhD THESES

(Degrees ongoing – Other than IUCAA)

Subhadeep De

Title: *Development of the optical set-up for Ytterbium ion optical frequency standards.*
Student: Lakhi Sharma (CSIR - National Physical Laboratory).

Neeraj Gupta

HI analysis of resolved galaxies in blind surveys with MeerKAT
Student: Eric Maina - SARAO, South Africa (co-supervisor, since 2019)

Testing large scale cosmology with MeerKAT
Student: Jonah Wagenveld - MPIfR, Germany (mentor, since 2019)

Suresh Doravari

Title: *Study of Limiting Noises in Advanced LIGO Pre-Stabilized Laser System*
Student: DivyaDileep (IAR, Gandhinagar)

*Introduction to Advanced LIGO & Opportunities for Research & Technological Innovation, followed by a panel discussion on LIGO-India,*Thapar Amateur Astronomers Society, Thapar Institute of Technology, Patiala,Eureka 5.0, Dec 5, 2021. (Online)

Introduction to Advanced LIGO & Opportunities for Research & Technological Innovation, TechExpo (Virtual Exhibition)-MindSparks'21, COEP, Oct 30, 2021 (Online).

Nishant Singh

Title: *On effects of small-scale turbulence on the acceleration of cosmic rays.*
Student: Mr SayanKundu (IIT-Indore) (Co-supervising)

Title: *On magnetic fields of disc galaxies.*
Student: Ms SubahSharma (Thapar Instituteof Engg and Tech, Patiala) (Currently co-supervising)

(f) SUPERVISION OF PROJECTS

Dipankar Bhattacharya

AvaniSahu (PVPIT, Pune)Identifying patterns in AstroSat CZTI temporal data via Machine Learning.

SukritJaiswal (IISER Pune) completed the project "*Study of the role of nuclear parameters in p-mode oscillations in Neutron Stars*" under the co-supervision of Bikram Keshari Pradhan

Radhika Agarwal (IIT Gandhinagar) is working on the project "*Role of vector self-interaction in Neutron Star properties*" under the co-supervision of Bikram Keshari Pradhan

Abhinaba Ghosh (IISER Kolkata) *CompOSE collaboration project* during the period May-July 2021.

VanshajKerni (IIT Roorkee) *CompOSE collaboration project*from August 2021 towards.

Suresh Doravari

AahanPalsole (SPPU)*Angular motion sensitivity limits of aLIGO optical levers.*

Nishant Mittal (IITB)*Improving OSEM sensitivity via phase sensitive detection and force feedback in seismic sensors.*

Karan Kedia, Aditi Chaluvadi, AvitRane (SPIT, Mumbai)*Study of OSEM noise in a modulated shadow sensor circuit.*

ShivarajKandhasamy

VishakhaPotdar (SPPU)*Virtual LIGO Gravitational Wave Detector*.
JunaidYousuf (University of Kashmir)*Effect of detector calibration uncertainties on the searches for stochastic GW backgrounds*.

Surhud More

Nikita Balodhi (IISER Tirupathi) *Study of Galaxy Morphology from large surveys using Artificial Intelligence.*

Esha Garg (IIT Roorkee) *Dark matter halo bias.*

Anupreeta More, Suresh Doravari, ShivarajKandhasamy

SiddhikaSriram (Software Engg., Tamil Nadu)*Decompose laser modes using CNN*.

Dipanjan Mukherjee

Sahyadri Krishnan (IISER Tirupati) remotely, for his Master's thesis inthe academic year 2021-2022.

Kanak Saha

Mr. Himanshi A. Bhisikar(IISER Pune) *Understanding star formation in NGC 4571 using UVIT and SDSS* (M.Sc. Final year thesis).

D. J. Saikia

Rushikesh N. Bhutkar (SavitribaiPhule Pune University, Pune) *Compact radio sources and the unification scheme* (co-supervised by YogeshChandola)

Rahul B. Musale (SavitribaiPhule Pune University, Pune) *Compact radio sources and their symmetry parameters* (co-supervised by YogeshChandola)

Nishant Singh

SoumilKelkar(IISER-Pune)*new paradigms of stellar convection* (Co-supervision)

Manasadevi P Thirugnanasambandam

PariveshChoudhary (IIT Kanpur) *10m prototype interferometer optical design in FPMI configuration.*

PariveshChoudhary (IIT Kanpur)*Length Sensing and Control Schemes for a Three-Mirror Coupled Cavity.*

(g) SEMINARS, COLLOQUIA, AND LECTURES

Tek Prasad Adhikari

X-ray Astronomy and XMM-Newton data analysis,X Ray Astronomy Workshop 7-10 March, 2022" organized by Tribhuvan University, Nepal, March 7, 2022.

Dipankar Bhattacharya

AstroSat Mission: Science Highlights, National Space Science Symposium, 01 Feb 2022. (online)

Debarati Chatterjee

Probing the Neutron Star interior with f-modes, Universidad de Valencia, Spain, April 9, 2021.

Imprints of the internal composition of neutron stars on gravitational wave emission, International Centre for Theoretical Sciences, Bengaluru, June 9, 2021

Signatures of Strangeness in Neutron Star Merger Remnants, workshop Probing Nuclear Physics with Neutron Star Mergers, European Centre for Theoretical Studies in Nuclear Physics and Related Areas, Trento, Italy, July 14, 2021

Role of Neutron Star interior composition in Gravitational Wave emission, IUCAA, Aug 6, 2021.
Gravitational Waves: window to an unforeseen Universe, NIT Surat, National Science Day, 28 Feb, 2022.

Neutron Stars: Astrophysical Probes of Extreme Matter, EXPLORE 2022 workshop, Astrophysical Laboratories of Fundamental Physics, 29 March, 2022.

Subhadeep De

Applications of the optical atomic clock as a quantum sensor, SVNIT, Surat, 14 March 2022.

Optical atomic clock: a quantum sensor to investigate fundamental science, CSIR-NPL, New Delhi, 04 March 2022.

IUCAA's optical atomic clock aiming for quantum metrology, IIT Delhi, 03 March 2022.

Quantum sensing using atomic clocks, IUCAA National Science Day 27 Feb. 2022.

Gulab Dewangan

Growing Black Holes: Accretion and mergers, Science Highlight of AstroSat,Kathmandu, Nepal, 15 – 20 May 2022.

Multi-wavelength study of Compactobjects with AstroSat, 2nd China-India Workshop on High Energy Astrophysics, 6-10 December, 2021.

An Introduction to Active Galactic Nuclei, NIUS Astronomy 2022, HBCSE (Mumbai), 19 June 2022.

Active Galactic Nuclei, Radio Astronomy School, RAWS2021, 30 December 2021.

Probing Central Engines of Active Galactic Nuclei with AstroSat, 3-day workshop on High Energy Astrophysics, 9-11 May 2022.

Apratim Ganguly

Detection and parameter estimation of Type-II lensed binary black hole mergers, Amaldi 14 on July 22, 2021.

Neeraj Gupta

The MeerKAT Absorption Line Survey: computing and big data challenges, HPC for Astronomy & Astrophysics, National SUpercomputing Mission, India, October 2021

The MeerKAT Absorption Line Survey: evolution of cold gas in galaxies, SKA Science Meeting as part of ASI, 2022.

Ranjan Gupta

Laboratory Study of Regolith Analogues,IUCAA Faculty Talk, August 2, 2021.[online]

An Introduction to Astronomy & Astrophysics, St. Joseph's College (Autonomous), Jakhama, Nagaland 17th of September, 2021.[online]

India's involvement in Mega Projects in Astronomy and A Career in Astronomy &Astrophyiscs, St. Joseph's College (Autonomous), Jakhama, Nagaland 17th of September, 2021.[online]

*Mega Projects in Astronomy,*International Lecture Series on Recent Advances on Pure and Applied Physics, Department of Physics, University of Science & Technology, Meghalaya (USTM), October, 1, 2021. (online)

Laboratory Study of Regolith Analogues – relevance to recent Asteroid regolith sample return missions, SNBNCBS, Kolkata on February 21, 2022.

ShivarajKandhasamy

Stochastic gravitational wave background, Build-a-detector workshop, IUCAA and Glasgow University, UK, June 3, 2021. [Online]

Status update on LIGO-India, LIGO-Virgo-KAGRA collaboration meeting, Louisiana State University, USA, March 16, 2022. [Online]

RanjeevMisra

Puzzle Challenges from AstroSat observations of X-ray binaries, ASI Meeting 2022, IIT Roorkee, March 2022.

*Black Holes in the Universe,*workshop on Emerging Trends in High Energy Astrophysics (ETHEA), Tezpur, March 2022

Black Holes in the Universe, workshop on Exploring the Cosmos 22, North Bengal Univ, Silguri, March 2022.

Spectral and Temporal behavior of Blazars, Second China-India Workshop on High Energy Astrophysics, Dec 2021.

Black Holes in the Universe, workshop on Emerging Trends in Physical Sciences, ICFAI Univ, Tripura, Oct 2021.

Black Holes in the Universe, SAAO, South Africa, Oct. 2021.

Some Questions: Mostly about black hole systems, IUCAA Retreat, August 2021

SanjitMitra

Hunting for Gravitational Waves from Ground and Space, 21st National Space Science Symposium (NSSS), Center of Excellence in Space Sciences India, Indian Institute of Science Education and Research Kolkata, Feb 3, 2022.

*Gravitational Waves & LIGO-India,*V.P.Mahavidyalaya, Vaijapur, Dist. Aurangabad, October 18, 2021. [Online]

Surhud More

Subaru HSC collaboration meeting invited talk, Mar 1, 2022
Weak lensing cosmology from the Subaru Hyper Suprime-Cam survey, Plenary talk at the 27th International Conference of International Academy of Physical Sciences on Advances in Relativity and Cosmology, Oct 28, 2021.

Weak lensing cosmology from the Subaru Hyper Suprime-Cam survey, IISC colloquium, Mar 4, 2022.

Weak lensing from the Subaru HSC Year 3 data, Subaru HSC collaboration meeting, March 1, 2022.

Dipanjan Mukherjee

Simulating the jet-ISM interaction in CSS-GPS galaxies, 6th Workshop on CSS and GPS radio sources, virtually, 10th-14th May, 2021. [Online]

Simulating the impact of jet-driven outflows on different scales, the virtual international conference from 14-18th June, 2021, organised by MPIA Hiedelberg and IIT Indore.

Simulating young evolving relativistic jets from supermassive black holes, MPIFR on April 27, 2021. [Online]

Simulating young evolving relativistic jets from supermassive black holes, University of Sheffields, Sept. 20, 2021. [Online]

How supermassive blackholes affect galaxy evolution, workshop on High Performance Computing for Astronomy and Astrophysics, organised jointly by the National Supercomputing Mission and IIT Kharagpur, Sept. 23, 2021. [Online]

Simulating young evolving relativistic jets from supermassive black holes, Indian Insititute of Science, Feb. 2, 2022. [Online]

Simulating young magnetised jets from supermassive black holes, Plenary talk at the annual meeting of the ASI 2022, March 27, 2022.

AseemParanjape

The radial acceleration relation in a ΛCDM universe, Sharif University of Technology, Tehran Nov 21, 2021. [Online]

The radial acceleration relation and the external field effect in a ΛCDM universe, DIPC, San Sebastian, Feb 4, 2022. [Online]

Kanak Saha

Exploring AstroSat UV Deep Field, AstronomischesInstitut, Ruhr-Universitдt Bochum, Germany, May 19, 2021

Exploring the AstroSat UV Deep Field, Galaxy Science Collaboration, LSST, June 1, 2021.

Exploring the AstroSat UV Deep Field, UNIVERSIDADE FEDERAL DO RIO DE JANEIRO, Brazil, July 13, 2020

Some aspects of galaxy research, IUCAA virtual retreat, IUCAA, August 13, 2021.

*Extreme UV photons from AstroSat UV Deep Field,*17th Prof. J.M. Sassarma Memorial Lecture, Scottish Church College, Nov 20, 2021

Lyman Continuum leakers from AstroSat UV Deep Field, Contributed presentation at NUVA virtual meeting, Nov 26 - 27, 2021 [Online]

The Extraordinary Escape of Extreme-UV photons, Coochbehar Panchanan Barma University, West Bengal, Dec 10, 2021.

Galaxies: Formation and evolution, Introductory workshop on Astronomy and Astrophysics, Kashmir Univ., Dec 18 - 19, 2021.

Extreme UV photons from high redshift galaxies, TIFR, Mumbai,Jan 19, 2022.

Extreme UV photons from distant galaxies, Institute for Plasma Research, Gandhinagar, Jan 24, 2022.

*Extreme UV photons from AstroSat UV Deep Field,*The Physical Society, IISER Thiruvananthapuram, Kerala, Jan 25, 2022.

*Extreme UV photons from high redshift galaxies,*Sixth Lecture Workshop on Trans-disciplinary Areas of Research and Teaching by Shanti Swarup Bhatnagar Awardee, DDU+NASI, India, Feb 2, 2022.

Extreme UV photons from distant galaxies, Institute of Science, GITAM Univ. Andhra Pradesh, Feb 21, 2022.

*Extreme UV photons from high redshift galaxies,*IISER Tirupati, Feb 23, 2022.

Probing Early galaxy formation using AstroSat UV Deep Field, the International Seminar on Astrophysics and Cosmology, Univ. Of North Bengal, March 03, 2022.

D. J. Saikia

Jet propagation in young radio galaxies, conference on Astrophysical jets and observational facilities : National perspective, ARIES, Nainital, April 05, 2021.

Recurrent jet activities in galaxies, S. M. Chitre Memorial Symposium on Frontiers in Astrophysics and Fluid Mechanics, UM-DAE-Centre for Excellence in Basic Sciences, Mumbai, May 08, 2021.

Exploring the Universe at radio wavelengths, Chancellor Lecture Series, Assam down town University, Guwahati,May 22, 2021.

A multi-messenger view of our Universe and the engineering challenges encountered, Space Technology Club, Assam Engineering College, Guwahati, November 08, 2021.

Nishant Singh

A Virtual Nordic Dynamo, seminaronMean-field dynamo action in shear flows: cases of fixed and fluctuatingkinetic helicity, April 13, 2021.

DurgeshTripathi

Solar Ultraviolet Imaging Telescope, PMOD Colloquium, April 13, 2021 [with SUITTeam][ONLINE]

The Aditya-L1 Mission: ISRO's observatory in space for solar observations, 15th Solar Terrestrial Physics symposium, Online, Feb 21-25, 2022 [Aditya-L1 team] [ONLINE]

Dynamics of the Solar Atmosphere, Department of Space Science and Astronomy, IIK Kanpur, 7th March 2022.

On the heating and Dynamics of Solar Transition Region, 40th Astronomical Society of India Meeting, 25-29 March 2022, IIT Roorkee and ARIES Nainital [with A. Rajhans, James Klimchuk][ONLINE]

Mg II core-to-wing ratio and its center to limb variation in sunspots from IRIS", Contributory talk, 40th Astronomical Society of India Meeting, 25-29 March 2022, IIT Roorkee and ARIES Nainital [MeghaAnand, DurgeshTripathi, Pradeep Kayshap][ONLINE]

Flows in enthalpy-based thermal evolution of loops, Third Parker Solar Probe Meeting, November 9, 2021[Abhishek Rajhans, DurgeshTripathi, Stephen Bradshaw, Vinay Kashyap, James Klimchuk] [Online]

Flows in enthalpy-based thermal evolution of loops, 16th European Solar Physics Meeting, September 8, 2021 [Abhishek Rajhans, DurgeshTripathi, Stephen Bradshaw, Vinay Kashyap, James Klimchuk] [Online]

Flows in enthalpy-based thermal evolution of loops, XVIIth Hvar Astrophysical Colloquium, September 21, 2021 [Abhishek Rajhans, DurgeshTripathi, Stephen Bradshaw, Vinay Kashyap, James Klimchuk] [Online]

The Impulsive Heating of Quiet Solar Corona, Physikalisch-MeteorologischeObservatorium Davos/World Radiation Center [PMOD/WRC], 11 May 2021, [ONLINE] [Vishal Upendran & DurgeshTripathi]

Solar wind prediction using deep learning, PSP scholar meeting, August 17, 2021 [ONLINE] [Upendran V, Cheung M, Hanasoge S, Krishnamurthi G].

Chromospheric and transition region dynamics in coronal holes and quiet Sun, the Hinode-14/IRIS-11 meeting from 25 - 28 October 2021 [ONLINE] [Vishal Upendran&DurgeshTripathi]

Solar wind prediction using deep learning, the Solar Orbiter International Science Working Group on Solar wind sources and connection, October 14, 2021 [ONLINE] [Upendran V, Cheung M, Hanasoge S, Krishnamurthi G]

On the formation solar wind and switchbacks, and Quiet Sun heating, 1-hour student seminar at IUCAA on 7 December 2021 [ONLINE] [Vishal Upendran&DurgeshTripathi]

Solar wind signatures in the chromosphere, American Geophysical Union (AGU) - 2021 from 1-31 December 2021. Received the Outstanding Student Presentation Award for this talk. [ONLINE] [Vishal Upendran&DurgeshTripathi].

On the formation solar wind and switchbacks, and Quiet Sun heating, the European Solar Physics Online Seminars (ESPOS) meeting, December 16, 2021 [ONLINE] [Vishal Upendran & Durgesh Tripathi]

Solar Ultraviolet Imaging Telescope (SUIT) Forward Modelling, 21st National Space Science Symposium, February 2022, [S. Roy, A. Bhasari, V. Witzke, D. Tripathi, P. Sreejith, A. N. Ramaprakash, S. Alexander, S. Solanki] [Online]

Solar Ultraviolet Imaging Telescope (SUIT) Forward Modelling, 40th Astronomical Society of India Meeting, March 25 – 29, 2022, IIT Roorkee and ARIES Nainital, [S. Roy, A.Bhasari, V. Witzke, D. Tripathi, P. Sreejith, A. N. Ramprakash, S. Alexander, S. Solanki]

Our Dynamic Sun, Introductory workshop in solar physics workshop at Fergusson College, Pune, August 24, 2021 (ONLINE)

Manasadevi P Thirugnanasambandam

*Building the quietest machine to listen to the sound of space-time,*Women's day with women scientists (Tara Govt College, Telangana), March 8, 2022.

(h) LECTURE COURSES

Dipankar Bhattacharya

Stellar Structure(4 lectures), IUCAA Summer School on Astronomy and Astrophysics, 10 – 13May 2021.

Debarati Chatterjee

Compact Stars I & II (2 lectures), IUCAA Introductory Summer School in Astronomy and Astrophysics + Refresher Course 2021, broadcast live on Youtube, 20 – 21May, 2021

Subhadeep De

Atomic Clocks, Introductory Summer School in Astronomy and Astrophysics (ISSAA) & the Refresher Course in Astronomy and Astrophysics (RCAA), 2021.

GulabDewangan

`X-ray astronomy & Active Galactic Nuclei', (2 lectures), Introductory Summer Scholl Summer School and Refresher Course at IUCAA, May – June2022.

Neeraj Gupta

ISM and Radio Astronomy,(3 lectures), Introductory summer school in Astronomy &Astrophysics May - June, 2020.

Ranjan Gupta

*Photometry & Spectroscopy,(2 lectures),*IUCAA Summer School in Astronomy &Astrophysics,17-18 May 2021, [Online]

ShivarajKandhasamy

Detector characterization and calibration of Advanced LIGO, Introductory Summer School in Astronomy and Astrophysics (ISSAA)& the Refresher Course in Astronomy and Astrophysics (RCAA) 2021, June 11, 2021. [Online]

RanjeevMisra

Radiative Processes, (2 lectures),IUCAA Summer School, June 2022.

SanjitMitra

Gravitational Waves (3 lectures), Introductory Summer School in Astronomy and Astrophysics (ISSAA) & the Refresher Course in Astronomy and Astrophysics (RCAA), IUCAA, Jun 9-11, 2021.

Introduction to Gravitational Wave Astronomy, (1 lecture) Introductory Workshop on Astronomy and Astrophysics, Department of Physics, University of Kashmir, December 18, 2021.

Gravitational Waves & LIGO-India,(2 lectures), Ad Astra - Astronomy and Science Club of BITS Pilani, Hyderabad Campus, Feb. 2, 2022. [Online]

Surhud More

Gravitational lensing (2 lectures), IUCAA Summer School cum Refresher Course, May 28 – June 2, 2021 *Cosmology*, (4 lectures), IUCAA Summer School cum Refresher Course, May 19,20, 21, 24, 2021.

Dipanjan Mukherjee

fluid simulations and hands-on training, (4 lectures), The Annual meeting of ASI 2022, March 25, 2022. [Online]

Radiative transfer,(4 Lectures), IUCAA Summer School in A&A 2021 *Computational astrophysics,* (1 lecture), IUCAA Summer School in A&A 2021

Kanak Saha

Galaxies, (3 lectures), IUCAA Summer School in A&A,May 2021

Astrophysics (18 lectures), MSc Class, CoochBehar Panchanan Barma University, May - June 2020.

D. J. Saikia

Radio Astronomy, (10 lectures), Centre for space science and technology education in Asia and the Pacific (Affiliated to the United Nations) Physical Research Laboratory, Ahmedabad 12th Post Graduate Course in Space and Atmospheric Science, March 2022, [Online]

Astrophysical jets and supermassive black holes (2 lectures), ISSAA/RCAA 2021, IUCAA, Pune, June 03 – 04, 2021.

Milky Way: an overview,(1 lecture), IUCAA-NCRA Radio Astronomy Winter School 2021, IUCAA, Pune, December 27, 2021.

Nishant Singh

Fluids and Plasma Physics,(4 lectures), IUCAA's summer school/RefresherCourse, May-June 2021.

(I) POPULAR / PUBLIC LECTURES

Debarati Chatterjee

Neutron Stars: Astrophysical Probes of Extreme Physics, Physics & Astronomy Club, IIT Delhi, March 11, 2022

Future opportunities for Indian girl students in Mega-Science projects: LIGO-India, Women's Day at Nehru Science Centre, Mumbai, March 3, 2021.

From Nuclei to Neutron Stars: Probing nuclear matter, Horizon Astronomy Club of IIT Madras, Sept 13, 2020.

ApratimGanguly

A gravitational-wave peak at the stellar graveyard, LIGO-India National Science Day 2022.

Neeraj Gupta

Square Kilometer Array (SKA): the largest radio telescope, IUCAA Science Day, Feb 28, 2022

SanjitMitra

An eventful beginning of Gravitational Wave Astronomy, Cosmology Club, Delhi Technological University, Oct. 28, 2021. [Online]

Surhud More

Ask an Astronomer series, by the ASI public outreach andeducation committee, Jan 8, 2022

D. J. Saikia

Non-violent conflict and social justice, International conference on impact of conflict on humanities, St. Pauls College, Bengaluru, June 25, 2021

Developing empathy and the importance of studying literature, Faculty Development Programme on New Trends in English studies, Tezpur University TLC and Department of English, Tezpur, January 17, 2022

Towards holistic liberal education, Faculty Development Programme, Exploring dynamics of the classroom NEP and NAAC perspective, St Pauls College, Bengaluru, January 25, 2022.

Kanak Saha

Astrophysics of Galaxies, ABN Seal College and Breakthrough Science Society, Coochbehar,
Dec. 21, 2021

(j) RADIO/TV PROGRAMMES

Debarati Chatterjee

Listening to the Cosmos, podcast (4 interviews) of international Gravitational Wave experts for the LIGO-India podcast channel:
1. Dr. Karan Jani (Vanderbilt University, Nashville)

2. Prof. Sanjeev Dhurandhar (IUCAA, Pune)

3. Prof. Anna Watts (University of Amsterdam)

Other Pedagogical activities by LIGO-India:

LIGO-India Instrument Science Training at IUCAA

The LIGO-India team at IUCAA has been engaged in imparting training to college students from across India to foster an interest in Gravitational Wave Detector related physics and technology. We have equipped a Design Cell with COMSOL, Solid Works, LabView software and related data acquisition hardware. These tools are being used to develop the apparatus we plan to build in the various laboratories where student projects are being undertaken. Over the past year we have built six single stage Suspension Training Modules (STM) and designed and fabricated the analog circuits that interface these suspensions to a LabView based control and data acquisition system. In addition, we have also built a Mock Advanced LIGO Control room in the Design Cell and also put together a stand alone Control and Data System (CDS) that is analogous to the CDS used on the LIGO sites. These various training modules are used by both undergrad students and our in-house LIGO-India personnel to impart to them the skills needed to commission and operate an Advanced LIGO detector.

We are engaged in building several laboratory facilities to house our experimental activity. A laboratory has been built in the Teacher Learning Center, IUCAA, which includes a cleanroom for an advanced optics laboratory. A laboratory for training teachers and engaging students in interferometry has also been developed in the same facility. Another laboratory for Gravitational Wave detector related instrument science is under development in the SITARA facility on the S. P. Pune University campus. These laboratory facilities would be used for both advanced research as well as training of personnel who would go on to contribute to the installation, commissioning and operation of the LIGO-India Observatory.

LI-EPO Blog *"Gravity Matters"* on LIGO-India website and social media channels continued to promote GW related sciences among general public, including features about Gravitational Wave science, Women in GW Astronomy, SciArt, articles in vernacular languages and more. Some of the new highlights include podcasts by distinguished gravitational wave personalities like Prof. Sanjeev Dhurandhar and Prof.TarunSouradeep, Behind-the-Scenes interviews with GW researchers and students.
https://www.ligo-india.in/gravitymatters/

"Listen to the Universe" children's book launch on GW discovery anniversary

An illustrated children's pop-up book in Marathi - "AikaBrahmand Kay Mhante" (Listen to the Universe) was launched on the occasion of the anniversary of the first direct detection of gravitational waves by LIGO. This book was written by the University of Glasgow, IUCAA SciPOP in collaboration with LIGO-India EPO (Manasadevi P Thirugnanasambandam) and supported partly by the Newton Bhabha Fund. The book has initially been published in Marathi, the native language of school children in the vicinity of the LIGO-India observatory site in Maharashtra. The book reading videos were premiered on LIGO-India EPO's YouTube channel on 14th September, 2021, in three languages, including Marathi, English as well as Hindi, in spirit of the Hindi Divas which was also celebrated on the same day.

LIMMA 2019 conference videos

A series of videos shot during the LIMMA conference in 2019, where the world's leading experts on gravitational wave detectors had gathered to discuss the new physics and astrophysics they may unravel in the era of LIGO-India, were released on various occasions during 2021. The interviewers included many of the LIGO-India team members (Sukanta Bose, Suresh Doravari, Vaibhav Savant). The videos are available on the LIGO-India Youtube channel - https://www.youtube.com/LIGOIndia

"Build a detector workshop" (May 31 - June 11, 2021)

A collaboration between the Newton-Bhabha and LIGO India partnership, this workshop taught students about gravitational wave (GW) science and the necessary considerations taken in order to design and concept-build a gravitational wave detector as well as the likely signals to be measured. A set of lectures were given on the main budget noises as well as the possible sources to detect. Assignments were given at the end of each lecture and discussed in each Q&A sessions. The last three days of the workshop focused on the teams designing their own gravitational wave detector with its own noise budget and source plot.

LOC: Debarati Chatterjee and Mariela Masso-Reid (Newton-Bhabha fund)

Volunteers for Drop-in session: Manasadevi P Thirugnanasambandam, Suresh Doravari and. ShivarajKandhasamy

National Science Day 2022 - organised by LI-EPO, streamed on YouTube

Public talks in English by Shasvath Kapadia (ICTS), ApratimGanguly (IUCAA), Prof Giles Hammond (Uni Glasgow), and in Marathi by Prof Varun Bhalerao (IIT Bombay)

Important LIGO-India press-releases

The LI-EPO team was involved in composing and distributing LIGO-India Scientific Collaboration (LISC) press releases among the local and national media in India. These included important announcements and events of LIGO Scientific Collaboration (LSC) for which working groups from the LISC had contributed actively. The work of Indian working groups was highlighted to ensure their visibility in the mainstream media. Some press releases were also translated to Hindi and Marathi. Some of the past press releases are listed below.

- O3alensing
  https://www.ligo-india.in/outreach/detections/o3alensing/
- O3IMBH
  https://www.ligo-india.in/outreach/detections/o3imbh/
- NSBH GW200105 & GW200115
  https://www.ligo-india.in/outreach/detections/nsbhdiscovery/
- O3 All sky, all frequency search
  https://www.ligo-india.in/outreach/detections/o3asaf/
- GWTC-3 catalog
  https://www.ligo-india.in/outreach/detections/o3bcatalog/
- O3b Tests of GR
  https://www.ligo-india.in/outreach/detections/o3btgr/

LI Press Conference - July 2, 2021

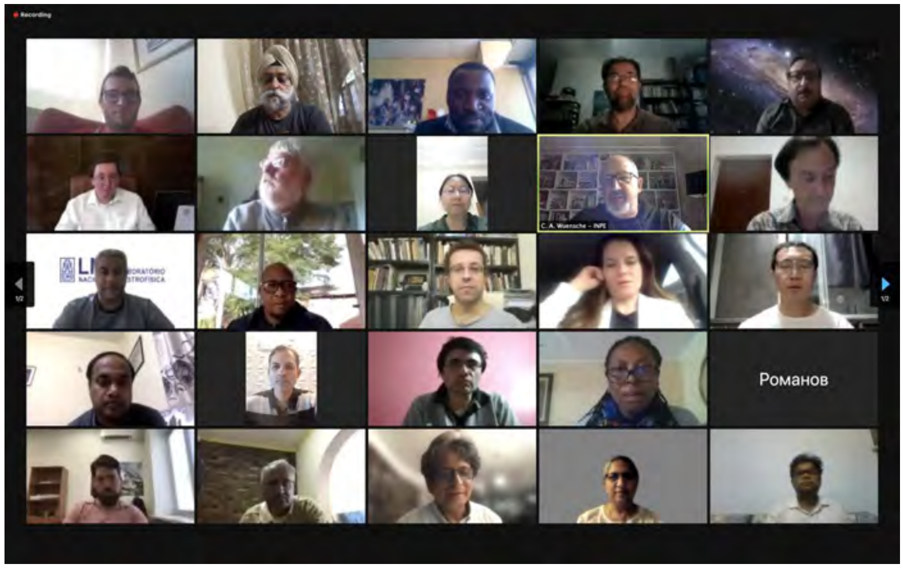
Panelist: Debarati Chatterjee, Anupreeta More, Somak Raychaudhuri, SanjitMitra, Sukanta Bose, BalaIyer, P. Ajith, Archana Pai, Varun Bhalerao, K. G. Arun, BhoosanGadre, Samir Dhurde

A press webinar was organised by LI-EPO to highlight "Recent milestones in GW Astronomy" particularly contributions from scientists from the LIGO-India Scientific Collaboration (LISC)

SCIENTIFIC MEETINGS AND OTHER EVENTS

Report on BRICS Astronomy Working Group (BAWG) meeting hosted online at IUCAA during May 19-20, 2021

The BRICS Astronomy Working Group (BAWG) provides a platform for BRICS member countries to collaborate in the field of astronomy. This year India has assumed the Presidency of BRICS Meetings and on this occasion, IUCAA and DST, New Delhi, jointly hosted an on line meeting of the 7th BRICS Astronomy Working Group (BAWG) during May 19-20, 2021 at IUCAA. Participants from all five countries (Brazil, Russia, India, China and South Africa) participated in this meeting with more than 50 participants consisting astronomers and government officials from these countries. The key scientific institutions that participated from the BRICS countries include the Tata Institute of Fundamental Research, Mumbai, Indian Institute of Astrophysics, Bengaluru, National Center for Radio Astrophysics, Pune, University of Delhi from India; National Laboratory on Astrophysics; Brazilian Center for Research in Physics, National Institute for Space Research from Brazil; Institute of Astronomy of the Russian Academy of Sciences from Russia; National Astronomical Observatories, Chinese Academy of Sciences from China; The South African Astronomical Society, DST South Africa, National Research Foundation, from South Africa.

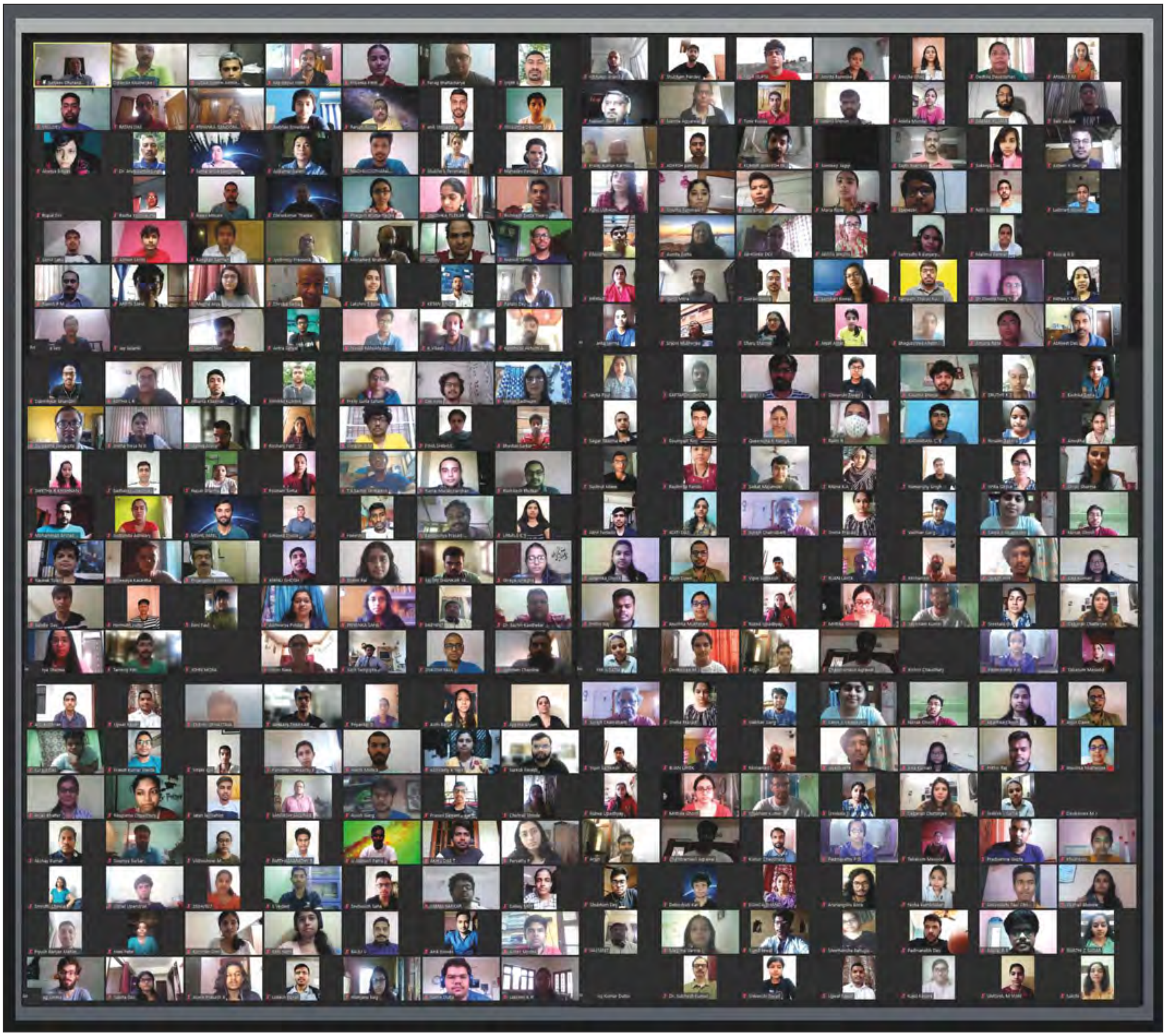


The first day of the meeting was on the presentations made by each of these countries on the progress of BRICS Flagship Project on "BRICS Intelligent Telescope and Data Network (BITDN)" followed by a discussion on the proposed formation "BRICS Astronomy Association". The second was primarily on the presentation of concluding remarks from the officials of the five respective countries followed by the preparation of the "Resolutions of the 7th Meeting of the BRICS Astronomy Working Group" by the BRICS Secretariat based at South Africa. The BAWG noted the importance of enhancing collaboration among astronomers from the BRICS countries. The respective Focal Points in each country will organize a discussion on the creation of BRICS Astronomy Association and report to the Secretariat for further actions. The BAWG thanked India for successfully hosting the 2021 meeting and China has offered to host the next BAWG meeting in 2022.

The BAWG was organized by Ranjan Gupta who is the current Chairman of the India BAWG.

Introductory Summer School on Astronomy and Astrophysics

The Introductory Summer School on Astronomy and Astrophysics (ISSAA 2021) for college and university students, which was held concurrently with the Refresher Course on Astronomy and Astrophysics (RCAA 2021) for college and university teachers, was conducted by IUCAA during May 10 – June 11, 2021. The events were conducted virtually through the Zoom video conferencing platform, and also simultaneously live streamed on YouTube. This year we had received a very enthusiastic interest for the Summer School, with more than about 1,300 applications. About 750 students, pursuing Bachelor's and Master's degrees in different scientific and technical disciplines from different Indian colleges and universities, were invited to attend the lectures. The intensive lecture series consisted of 30 different topics, ranging from the basic pedagogical lectures on introductory astronomy to more advanced talks on cutting edge research. The broad range of lectures were meant to introduce the fundamentals of astronomy and astrophysics, as well as give them a flavour of the current developments in the frontier research topics and techniques. The lectures were delivered by faculty, postdocs, and PhD students from IUCAA, along with a two-part guest lectures on Astrophysical Turbulence by Dhrubaditya Mitra (NORDITA, Sweden). This year, we also had live demonstrations of several astronomy related experiments to encourage the participants to gain more hands-on experience on astronomy, and the topics included experiments on radio astronomy, demonstration of building a small telescope and its usage, and a tutorial on an open source planetarium software Stellarium. The live demonstrations were organised jointly by members of the IUCAA Teaching and Learning Centre (TLC) and the IUCAA astronomy outreach team. Recordings of most of the lectures and demonstrations have



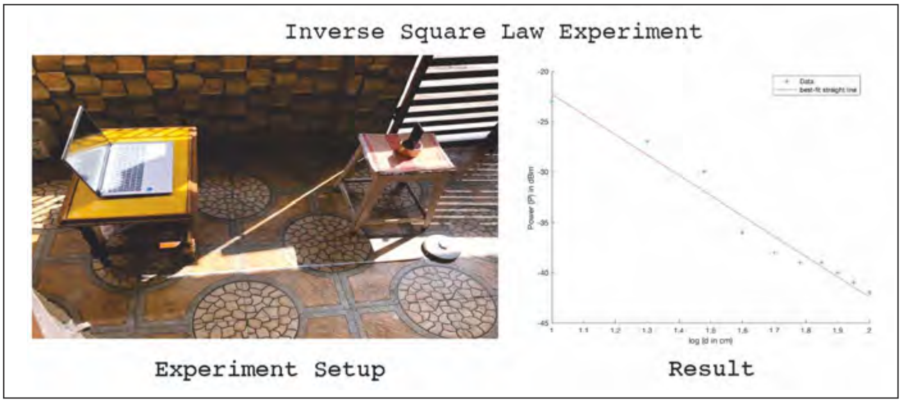
been live streamed on YouTube, and subsequently made available for viewing, which till date has garnered around 20,000 views in total, and still counting. The events were strongly supported by the entire staff of IUCAA. Zoom video conferencing and YouTube live streaming were coordinated by Santosh Jagade, and Sagar Bhosale (both from IUCAA). Dipanjan Mukherjee, Nishant Singh, and Surhud More (all from IUCAA) were the faculty coordinators.

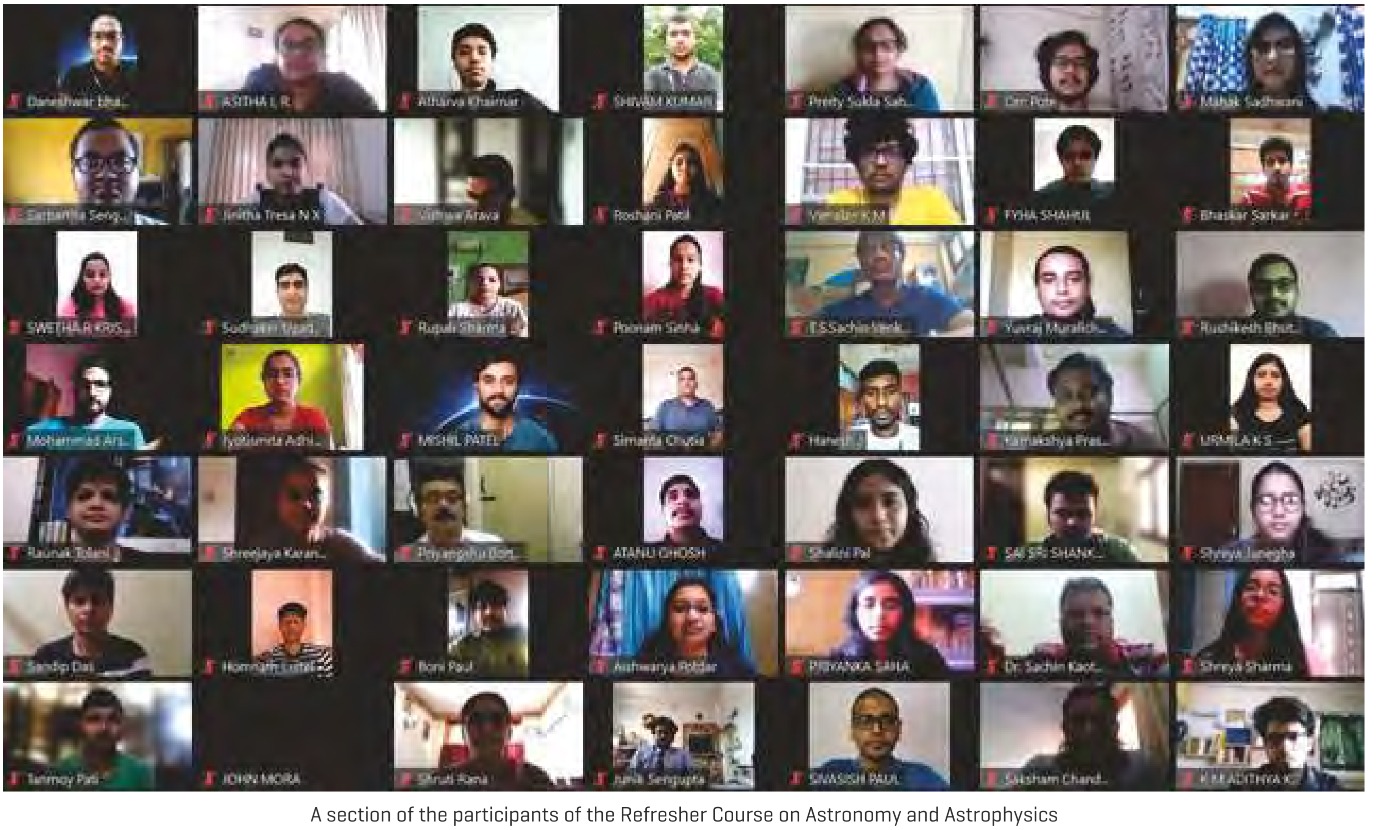
ASTRONOMY CENTRE FOR EDUCATORS

Teaching Learning Centre and National Resource Centre

Refresher Course on Astronomy and Astrophysics

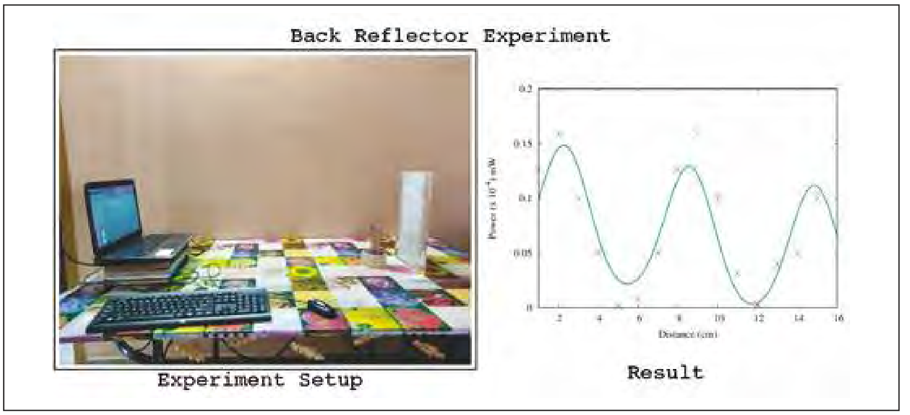
The Refresher Course on Astronomy and Astrophysics (RCAA 2021) for college and university teachers, which was organized concurrently with the Introductory Summer School on Astronomy and Astrophysics (ISSAA 2021), was held during May 10 – June 11, 2021. Due to the prevailing pandemic situation, RCAA was held online with the participants interacting via Zoom. The presentations were also live streamed via YouTube. About 200faculty members, and early career researchers from colleges and universities across the country were invited to participate. In addition to the lectures, which covered some of the basics and also many frontier areas of research in astronomy and astrophysics, there were a number of hands-on activities, which the participants could do at home. The participants conducted these activities in groups, which also facilitated their learning from one another. The activities included astronomy-themed experiments using gadgets available at their disposal, assignments based on Stellarium, an open source planetarium software package, and making pedagogical videos on astronomical topics they learnt during the course. The astronomy-themed experiments were based on understanding radio wave





A section of the participants of the Refresher Course on Astronomy and Astrophysics propagation using a mobile phone, and a laptop as a transmitter and receiver. These experiments designed by Jameer Manur, Ashish Mhaske, and Prakash Arumugasamy (all from the Teaching Learning Centre, Astronomy Centre for Educators, IUCAA), involved exploring the inverse-square law, and the effect of putting a reflector. The set up and results from different groups are shown in the accompanying figures. The participants made several short and informative pedagogical videos, and found the Stellarium assignments given by Prakash Arumugasamy valuable, for using this package in their regular classroom teaching.

Also, there were Optical Telescope Primer sessions during May 18 – 19, 2021, which covered the basics of optics and telescopes as well as step-by-step demonstration on how to set-up different types of telescopes, and how one can attach cameras, accessories, and mobile phones to them, in order to capture images. Projects were presented by Samir Dhurde (IUCAA) that the participants could try on their own, and carry out meaningful observations and measurements. Atharva Pathak (IUCAA) demonstrated the setup of the telescope and its accessories, as well as explained the working of various types of telescopes and instruments.

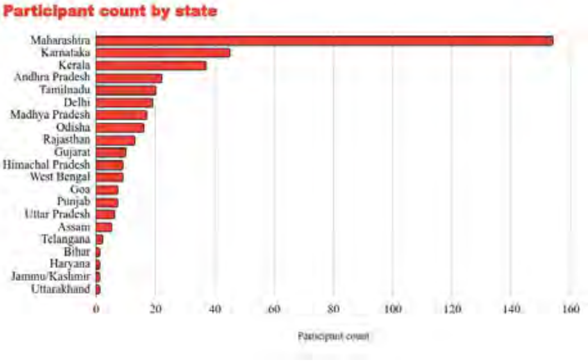


The Refresher Course was coordinated by Dipanjan Mukherjee, Nishant Singh, and Surhud More, with Dhruba J. Saikia (IUCAA) and the team at ACE TLC overseeing the evaluations of the participants' understanding of the course material.

Guru Dhwani 2021:
Probing the Signals from Jupiter

Guru Dhwani 2021, a national level antenna design challenge competition has been organized by Astro Club, Fergusson College (Autonomous), Pune, in collaboration with the Teaching Learning Centre (TLC) of IUCAA. The aim of this competition is to design and simulate an antenna system sensitive to the very low-frequency radio emission from Jupiter. A total of 58 teams consisting of 416 faculty members and students from about 20 states in the country have registered to participate in the competition. The final designs are to be submitted by January 16, 2022. It has been planned that the working designs will be installed in the different participating educational institutions to observe both Jupiter and the Sun.

◄ Poster announcing Guru Dhwani



Distribution of participants ►

Workshop on Online Pedagogy and Evaluation

A section of the participants of the Workshop on Online Pedagogy and Evaluation

The Workshop on Online Pedagogy and Evaluation was held online on June 30, 2021, to discuss and share experiences on these aspects during the current pandemic. The workshop was attended by about fifty IUCAA Associates and astronomy educators. The introductory remarks by Somak Raychaudhury, Kandaswamy Subramanian, and Dhruba J. Saikia (all from IUCAA) were followed by a detailed presentation by G. Ambika (IISER, Tirupati) on their experiences with online teaching and evaluation. Sahana Murthy (Educational Technology Interdisciplinary Programme, IIT – Bombay, Mumbai) gave a lucid presentation on enhancing online learning processes, shared results of some of their surveys, and made suggestions for best practices. Ramana Telidevara (Founder and CEO, CodeTantra) gave a very detailed description of their assessment platform with online remote proctoring, which generated a lot of discussions. Prakash Arumugasamy gave an overview of our evaluation processes using Google and Moodle, while Sukanta Deb (Cotton University, Guwahati) made a presentation on how to make pedagogical videos using the open source Linux platform for online teaching.

IUCAA ACE Repository of Experiments

Astronomy-themed IUCAA ACE Repository of Experiments has been initiated, hosted by the IUCAA Library. The repository is divided into five categories, three of these are based on the wavelengths of observations in the electromagnetic spectrum, the fourth one is on gravitational waves, and the fifth one is of a more general nature. These are categorized as (i) radio, (ii) infrared, optical and ultraviolet, (iii) high-energy astrophysics, which includes X-rays and gamma-rays, (iv) gravitational waves, and (v) others. The link to the Repository is:
http://repository.iucaa.in:8080/jspui/handle/11007/4545

The repository has been started with a few radio astronomy related experiments, which could be done at home. These were part of the experiments offered during the Radio Astronomy Winter School – 2020, and IUCAA Refresher Course on Astronomy and Astrophysics – 2021. Members of the community are encouraged to contribute to the Repository. Those wishing to do so are requested to email us at nrciucaa@gmail.com

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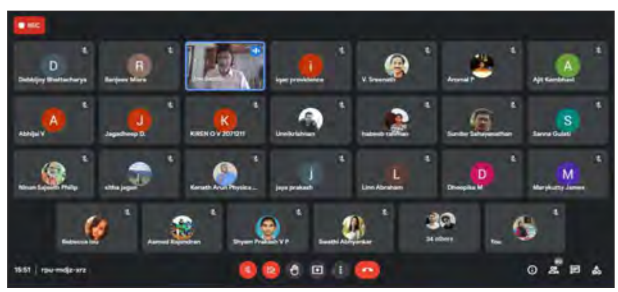
Research In Astronomy: Opportunities and Challenges

Seventh Southern Regional Meeting
September 8-10, 2021

The Department of Physics, Mar Thoma College, Chungathara and the Providence Women's College, Calicut conducted the Regional Astronomy Meeting for the Southern region of India, in association with IUCAA, during September 8 - 10, 2021. The purpose of the meeting was to help the researchers of the region in updating themselves with the latest developments in the field and in identifying new research areas and problems. This was also envisaged to serve as a platform for interacting with scientists from the field and for fostering further teamwork and collaborations. Due to the pandemic Covid-19, we used the online medium for the meeting.

The meeting was inaugurated by Somak Raychaudhury, Director, Inter-University Centre for Astronomy and Astrophysics, Pune and felicitated by Kandaswamy Subramanian, Dean, IUCAA. The plenary lectures on the theme of Future Astronomy in India was delivered in the mornings by Bala Iyer (ICTS, Bengaluru), Shyama Narendranath (ISAC, Bengaluru) and Ajit Parameswaran (ICTS, Bengaluru). Due to the enhanced response to the meeting, the sessions were arranged in parallel. During these three days of the meeting, we had presentations from research scholars interspersed with the overview talks by senior researchers, spread into eight sessions. The meeting discussed the areas of research including Cosmology, Stellar Astrophysics, X-ray Astronomy, Extragalactic Astronomy, ISM and galactic astronomy and Radio Astronomy. There were a few presentations by Post Graduate students on the curricular projects they did in the field of Astrophysics. Altogether there were three plenary Lectures, 5 Special review talks, 14 invited review talks, 35 contributed talks and 11 UG/ PG presentations. The special talks on the seminal work from the region which attracted media attention were arranged every day in the morning session, just after the plenary lectures. To compensate for the usual discussions and interactions which used to happen in the 'physical' meetings, two interaction sessions were also arranged in the evenings of September 8th and 9th. This year, the consolidated abstract book, including all abstracts of the talks in the meeting, was released on the third day of the workshop. The workshop was coordinated by Sheelu Abraham (Mar Thoma College, Chungathara), Jeena K (Providence Women's College, College in Kozhikode) and Ranjeev Misra (IUCAA).



The Thirty-Third Foundation Day Lecture

The 33rd Foundation Day Lecture of IUCAA was delivered by Dr. Shekhar C. Mande on Wednesday, December 29, 2021.

Shekhar C. Mande is a Structural and Computational Biologist. He joined CSIR in mid-October 2018 as the Director General and served till April 2022. He has also served as the Secretary of the Department of Scientific and Industrial Research (DSIR), Ministry of Science and Technology. Before this, he was the Director of the National Centre for Cell Science, Pune.

He was awarded 2005 the Shanti Swarup Bhatnagar Prize for Science and Technology, the highest science award in India, in the Biological sciences category. Mande completed his M.Sc. in Physics from the University of Nagpur in 1984. In 1991, he earned his PhD in Molecular Biophysics, from the Indian Institute of Science, Bangalore. Following his PhD, he joined Wim G. J. Hol as a Postdoctoral researcher at Rijksuniversiteit Groningen in the Netherlands. He served as the chair of the National Committee for the International Union of Crystallography for the Indian National Science Academy, New Delhi.

As an ode to 75 years of Independent India, Professor Munde delivered a talk on " India's Science and Technology Journey in the Post-Independence Era". He shared his views on the contemporary history of Science and Technology and spoke about the Indian contributions to scientific developments from ancient times. A journey of the resurrection from the dark age period to becoming a flourishing nation after the colonial powers left the country. With suitable examples, he argued [AP: argued] that post-independent India has sufficiently developed to address the most fundamental questions of the origins of modern humans in South Asia. He walked the audience through the journey of building and Nurturing India's Science and Technology ecosystem, narrating the conception and formation of one of the first publicly funded organisations Council of Scientific & Industrial Research (CSIR) in 1942 followed by the other national organisations to encourage the development of science and technology in the country. Having recognized the fact that discoveries of science made in the laboratories can be taken to society by strong collaborations with the industry led to the involvement of Philanthropists [AP: philanthropists] and the general public during the early phases of its development leading to the formation of Tata Institutes of Fundamental Research, (TIFR).

He spoke of the Atomic Energy Commission and India's efforts in strengthening the country's atomic energy programme with TIFR as the centre for all large-scale nuclear physics in India. With the help of a graph, he elaborately discussed the S&T drivers in India through the times while explaining the difficulties faced during the early implementation of democracy.

India has demonstrated effectively by the adoption of science and technology that the `nation is now at par with the rest of the world as regards its intellectual and technological power. One major example is its role in the mitigation of COVID-19 with its SARS-COV-2 diagnostic innovations He devoted a few minutes to highlighting the outstanding Indian accomplishments in the field of biotechnology by talking about the contributions of G N Ramachandran and Sambhu Nath De to the subject. He emphasized the need for large collaborative work between different fields of fundamental sciences to address some of the most challenging problems in natural sciences. He concluded his lecture by briefly talking about a few future technological aspirations of the nation that are currently in process. This enlightening talk came to an end with an interactive Q&A session.

Due to the ongoing pandemic, the Lecture was held entirely online, with a live YouTube stream that drew in about 470 viewers as well as a smaller, interactive audience on Zoom.

Watch this lecture here: **https://www.youtube.com/watch?v=opUo-KBgHHs**

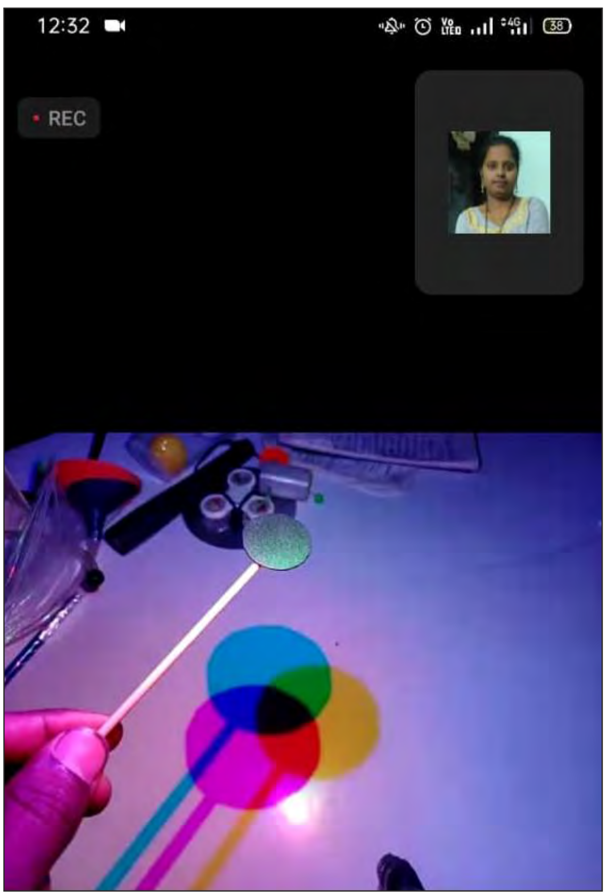
PUBLIC OUTREACH HIGHLIGHTS

The pandemic has opened a plethora of ways to combine virtual and physical experiences. The IUCAA Scipop team was able to reach out to a maximum number of students from all over the world and introduce them to the mysteries of the universe virtually. The team organised various interesting sessions and interactive workshops for students and teachers as well as the general public. With the help of innovative teaching aids and technology, various events were made accessible to everyone.

SPECIAL EVENTS

Lunar Occultation – 17 April 2021

IUCAA SciPOP arranged a live webcast of Lunar Occultation of Mars on its YouTube channel with more than 8000 attendees. Mr Ayan Saha from Tripura joined to demonstrate the Immersion (Ingress) of Mars and a team of Amateur Astronomers from Jyotirvidya Parisanstha, Pune, demonstrated the Emersion (Egress) of the occultation. The Program began with an introduction and description of the event by Mr.Samir Dhurde in 4 languages viz. English, Hindi, Marathi and Bengali. The program was hosted by Mr Atharva Pathak. Mr Tushar Purohit conducted a virtual sky session in Hindi.



A special series for Zilla Parishad (ZP) schools, Pune

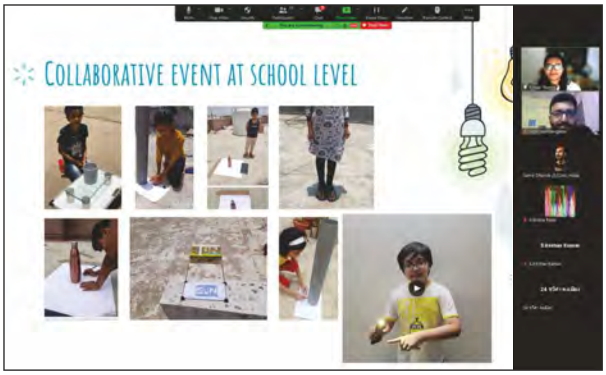
A series of online interactions in Marathi, specially designed for ZP schools in and around the Pune district, was introduced in September 2021, in coordination with the ZP Education Office.

In the series, every Saturday had a session dedicated to different audience groups based on surrounding objects and phenomena. A session on "Fire and Earth", coordinated and executed by Shivani Pethe and Swanand Athlye as a part of this special series on the 5 elements of the universe or the panchamahabhutas on the 1st of January concluding the series.

This series also covered various sessions on Science Toys/ Experiments, Demonstrations, Basic astronomy and teachers' training programmes.

The programme was initiated by Sonal Thorve and coordinated by Rupesh Labade with Shivani Pethe, Atharva Pathak and Tushar Purohit who conducted the various sessions.

As an extension to this, the Vidnyan Adhyapak Sangh Pune, VASP, initiated in the year 2021 was executed successfully. Teachers under this program were divided into groups for different subjects like maths, chemistry, physics, biology and environmental science. They were motivated to design and develop new models, experiments and toys that would further be documented and featured on IUCAA youtube channel on the occasion of science day. This program was conceptualized and effectively executed by Sonal Thorve, Samir Dhurde, Rupesh Labade, Shivani Pethe and Swanand Athlye.

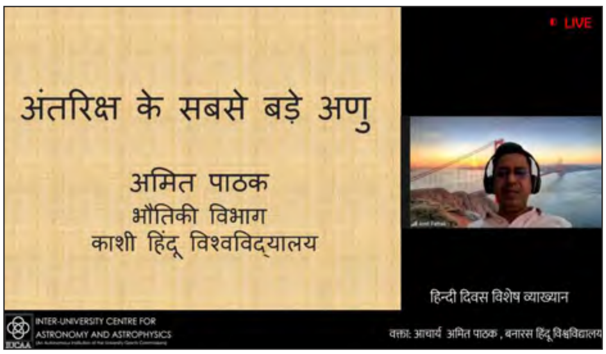


Zero Shadow Day Event with Kothari International School - 17 July, 25 July, 21 August 2021

The Zero Shadow Day (ZSD) Celebrations with Kothari International School consisted of an inter-school event on August 21. Students from 7 schools across Delhi, Maharashtra, Gujarat and Madhya Pradesh presented their findings and experiences of the experiments they performed.

Around 150 students and teachers attended the online event and learnt about the ZSD event. Mr Samir Dhurde was invited as a guest to mark the culmination of the event. The celebrations concluded with an interactive session with the students.

The event was designed and coordinated by Sonal Thorve with the help of teacher organisers.



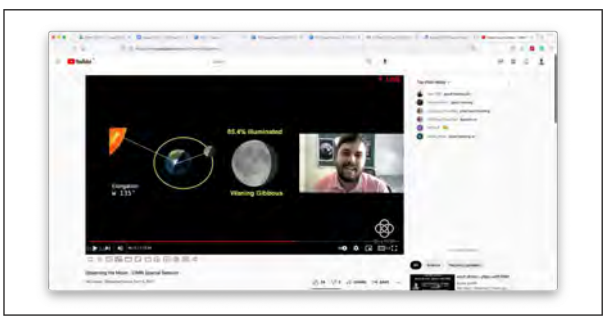
Hindi Diwas

On the occasion of Hindi Diwas, the 14th of September 2021, IUCAA arranged 2 special sessions in Hindi.

Prof. Somak Raychaudhury and Prof. Durgesh Tripathi welcomed and introduced the panel followed by a talk by Prof. Subhadeep De on "Sundial to Atomic Clock: For Accurate Time Keeping and Fundamental Science".

The day consisted of talks by Prof. Amit Pathak on "Largest Atoms in the Universe" and Prof. Durgesh Tripathi on "An overview of Hindi Pakhwada, a 15-day program full of Hindi Activities".

The viewers indulged in an interactive Q&A session at the end of the talks.



International Observe the Moon Night - 16th October

October 16th was celebrated as **"International Observe the Moon Night"** all over the world, and as a part of this, IUCAA SciPOP arranged 2 sessions on "Observing the Moon" as well as "Telescopic Viewing of the Moon" that were coordinated by Atharva Pathak and Tushar Purohit. About 300 people joined this event.

Outreach in Hingoli - 24th to 26th November 2021

LIGO-India - Education and Public Outreach (LIEPO) organised a series of public outreach activities from 24th to 26th November 2021 in the region surrounding the LIGO-India site. An introductory GW talk was conducted at the ZP Girls High School (Hingoli), ABM English School (Hingoli), ZP High School (Puyana) and Saraswati Foundation Academy (Hingoli). It included a demonstration of the Michelson Interferometer for explaining the basic working principle of gravitational-wave detectors like LIGO. This was followed by a talk on the basics of telescopes. More than 330 secondary school students were present for the talk. A telescope training session was conducted at the ZP High School in Kondhur village. The school teachers were instructed about the best practices of handling and using a telescope in reference to a 6-inch Dobsonian telescope that they had recently procured. A stargazing session was conducted after this which was open to the general public. Stargazing sessions were also conducted at the ZP High School (Puyana) and Saraswati Foundation Academy (Hingoli). They received an overwhelming response with more than 1250 people attending. These comprised secondary school students and the general public. The activities were coordinated by Ankit Bhandari (LIEPO Assistant at IUCAA) with help from freelance telescope resource person Tushar Purohit.

Astronomy@Home award by IAU

The IAU recognized the various efforts across the world to put up online outreach to keep the public connected with our astronomy communities during the summer of 2020. Out of the selected 50 events from 31 different countries, IUCAA SciPOP team won the first prize in the **"Community Engagement"** category and got honourable mentions for the **"Most Innovative Event"** and the **"Largest Number of Registered Events"**. Activities like Astronomy Crosswords, along with Sci-Fi Enterprise - Science Fiction Story and Poetry Writing Competition, Moon Challenge, Zero Shadow day and the live webcast during the Annular Solar Eclipse of June 2020, were considered for these awards. The team led by Samir Dhurde consisting of Shivom Gupta, Sonal Thorve, Ishan Shinde and Atharva Pathak worked in creative ways making use of technology to make sure that astronomy reaches people regardless of the various obstacles.

World Space Week - 4th to 10th October 2021

World Space Week (4th to 10th October) is an international celebration of science and technology and their contribution to the betterment of the human condition. IUCAA participated in numerous programs worldwide to join this celebration of Space and Astronomy. Many programs were coordinated and talks were given by Atharva Pathak, Shivani Pethe, Rupesh Labade, Tushar Purohit and Samir Dhurde at many different places. With a total of over 500 attendees from across the globe.

3rd Shaw-IAU Workshop on Astronomy for Education - 12th to 15th October 2021

Shaw-IAU Workshop on Astronomy for Education was organised from 12th October to 15th October 2021. IUCAA Scipop presented a poster and a talk at the 3rd Shaw-IAU Workshop on Astronomy for education. The Poster titled "**Bringing Astronomy to the students and Teachers using AppStronomy**" was presented by Rupesh Labade. A talk Authored by Mr Amit Dhakulkar on "**Platforms to create your own astronomy courses**" was co-authored by Samir Dhurde and Atharva Pathak of IUCAA SciPOP. Samir Dhurde also acted as a chair for the session about Online Resources for Astronomy Education and also was a part of the organising committee for the workshop.

TELESCOPE MAKING

As a part of outreach, IUCAA Scipop team conducts various sessions on telescope making and handling for teachers and students all over the country. A session on **"Astronomy and telescope handling" and an online session on telescope making were organised on the 9th of July and 4th of August respectively.**

It included a Teachers' training workshop organized by Discovery Science Center [Kerwadi] and Samaj Kalyan Ashram school [Naygao in Nanded] and at Wada, near Rajgurunagar. Both these workshops were conducted by Tushar Purohit from IUCAA SciPop. A total of 28 and 30 teachers respectively attended these workshops and learnt about telescope handling, operating and conducting skywatches

The online session was on **refractor telescope making** and it was organized by Brijesh Dixit, from Global Science Club [VIPNET CLUB] from **21 August 2021 to 19 September 2021**. In this series, Tushar Purohit from IUCAA Scipop gave a talk and demo on telescope making. 65 students from all over India participated in this workshop and made 50mm diameter telescopes.

A workshop on Choosing your Telescope was conducted in two phases on the 23rd of October and the 13th of November respectively.

The first part called Episode 1- Beginner Level premiered on 23rd October 2021. This session included **choosing the best set-up** for observing the Planets, bright nebulae, and star clusters. This session was a part of the Telescope making series which included guidance on choosing the best possible set-up for telescope purchase and assembly for simple viewing and observations of deep-sky objects and planets. About 700 people have viewed the session online.

The second part of the same series was held on 13th November 2021 in which the viewers were given a glimpse of how to choose the best set-up for Astrophotography and small astronomy projects. About 100+ people have viewed the session online. The sessions were coordinated by Atharva Pathak, Tushar Purohit, and Samir Dhurde. More than 1600 people have viewed the entire series of sessions online so far.

SCIENCE TOYS / ASTRONOMY TALKS / SKYWATCH

The IUCAA Scipop team religiously strives to make science fun and interesting for children through fun toys and experiments and also works on developing various teaching aids. Sessions on demonstrations of these toys were conducted all over the country.

A one-day program for students from all over Kolhapur from different schools was organised by the Rajaram College, Kolhapur on 11th December 2021. Shivani Pethe and Atharva Pathak were invited as resource persons. Around 100 students and 15 teachers attended this session.

Following this, a sky-watching session was conducted at night and attended by around 200 people. Three telescopes were set up to show Venus, Saturn, Jupiter and the moon.

A Two-day long online workshop was conducted on the 24th and 25th of January 2022 for students of SNDT college and Sathe College, Mumbai. It included Science Toys Demonstration Session with Hands-on Activities and an NLP session. Similar sessions were conducted at Savitribai Phule School, Mahatma Phule Krishi Vidyapeeth, Rahuri and Samata International School, Shrirampur.

A total of more than 1000 people benefitted from these sessions from April 2021- March 2022. The attendees included school and college students, teachers and general astronomy enthusiasts from all over the country. Jamir Manur from TLC was also invited as a Resource person to conduct the stargazing session.

The sessions were organised for the following educational institutes along with the ones mentioned above.:

- Rani Laxmi bai Mulinchi Sainiki Shala, Pirangut
- S. P. College
- Dighanchi Girls High School, Dighanchi.
- Madhyamik High School, Gargoti in INYAS Science camp by D Y Patil University, Kolhapur.
- Diploma Engineering Students at Zeal Polytechnic, Narhe.
- Diploma Engineering Students at P K Technical Campus, Chakan

TEACHER TRAINING PROGRAMMES

ZSD Educators' Workshop – 01 – 02 May and 08 – 09 May 2021

A couple of 2-Day Workshops on Zero Shadow Day were co-organized by Inter-University Centre for Astronomy & Astrophysics, Vigyan Prasar, and ASI POEC on May 01 - 02 (English) and May 08 – 09 (Hindi). Educators from all across the nation participated in these workshops. The workshop was coordinated by Samir Dhurde. The workshop consisted of sessions on zero shadow day and ways in which one can communicate in the most effective ways to children.

IUCAA Online Teachers Trainings - State (IOTT) and National (INLOTT) level

Special programs for teachers were arranged virtually on 28-29th August 2021 for the teachers in Maharashtra and from 4-5th September 2021 for teachers across India. While IOTT was held completely in Marathi, INLOTT had English as the language of communication. Nearly 500 teachers participated in this workshop from all over Maharashtra in IOTT and INLOTT was attended by about 700 teachers. The topics covered in the sessions were 'Basic Astronomy' and 'Science at the school level'. Rupesh Labade from the SciPop team coordinated this event. Sessions were conducted by Rupesh Labade, Atharva Pathak, Shivani Pethe and Tushar Purohit.

A two-hour virtual teacher training program was also held on 13th July 2021 by Rupesh Labade at the Agastya International Foundation. A total of 400 teachers participated in this training.

Teachers training program - 22nd December 2021

Tushar Purohit and Maharudra Mate from IUCAA and Sonal Thorve from IISER, Pune conducted a teachers training program for ZP teachers, Udgir region. The astronomy training workshop had 180 teachers from various Tehsils participating. This program was organised by ZP Udgir and Birla Open Minds international school.

NATIONAL SCIENCE DAY 2022

Celebrating Science!

The National Science Day 2022, was very thoughtfully chosen to be celebrated on a Sunday to make sure children could attend the session without sacrificing their schools and tuition. The team organised a virtual tour of the entire IUCAA campus with inbuilt hotspots for pre-recorded lectures, posters and exhibits on various topics. These hotspots were located everywhere around campus which made the experience of online campus visits more realistic and lively.

National Science Day 2022 "open day" event online: 27 February 2022

Not letting the third wave affect the enthusiasm of celebrating the traditional science day also known as the " Open Day ", February 27th, Sunday was when the gates of IUCAA were open to the public, **VIRTUALLY**! The entire event was conducted online, allowing students from not only the country but from any part of the world to join in the celebrations. To make the experience memorable, the organising team came up with interesting and interactive combinations of online platforms. An entirely virtual tour of the campus, which could also run from a smartphone, and could allow a virtual visitor to look at actual visuals from the campus was created in Kuula. Along with the walkaround, visitors could also view posters and demo videos within the same tour at their own pace. This platform reached more than **20,000 viewers**. This was also accompanied by live talks and interactive sessions throughout the day on Youtube

Followed by an enriching and interesting session called '**Ask a scientist**'. The session was hosted by IUCAA scientists Surhud More and Anupreeta More who asked various questions to **Jayant. V. Narlikar, Mangala Narlikar & Somak Raychaudhury.** This question-answer session turned out to be everyone's favourite. People from all over India submitted questions via IUCAA's social media channels. Live questions were also accepted and patiently answered.

On this occasion, the teachers of Vidnyan Adhyapak Sangha Pune (VASP) also made and shared some videos of newly curated Science Toys and activities in Chemistry. This was a part of an ongoing project of VASP and IUCAA. Some videos were featured in the event along with the announcement of the result of various student competitions taken in February 2022.

The National Science Day 2022 continued into the evening with a wonderful and relevant Public Lecture titled - "Unfolding New Secrets of the Universe with James Webb Space Telescope" by Swara Ravindranath, (STSCI, NASA)

The program concluded with an Online Public Sky Watch session.

National Science Day competitions:

This year, due to the COVID-19 pandemic the Urban IUCAA National Science Day competitions were organised on an online platform. But the rural competitions were conducted offline at Government Polytechnic, Awasari on the 18th of February 2022, strictly following all covid protocols. Various competitions like poetry, essay, drawing and quiz were conducted. A total of 260 students from 52 different schools in Pune city and the Ambegaon taluka region enthusiastically participated in them. The Urban competitions were held on 21 February. All the topics of these competitions were based on General Science and Astronomy which were designed and executed with the help of research students and faculty from IUCAA. They also helped in finalising the results of these competitions.

PULASTYA

The Annual Pulastya Science Festival 2021 was organised on the 8th and 9th of November 2021. This is an annual event that is organised in memory of **Late Pu. La. Deshpande** is one of the many famous events coordinated and conducted by IUCAA scipop for many years now. This year the festival included sessions on Science with Rangoli, firecrackers and their alternatives, Moon Lantern and Celestial Fireworks. The sessions were arranged and coordinated by the SciPOP Team: Shivani Pethe, Atharva Pathak, Rupesh Labade, Tushar Purohit, Swanand Athalye, Maharudra Mate, and Samir Dhurde. A compilation of all these topics was premiered in two different languages on two days, in English and Marathi on 8th and 9th November respectively. A Live Sky session was planned and planets were shown through the telescopes live over YouTube. This session was planned and coordinated by Atharva Pathak, Tushar Purohit, Ankit Bhandari and Prathamesh Jaju. The overall participation was 2000+ views on YouTube.

CONFERENCES

CAP 2021 Virtual Conference – 24 – 27 May 2021

The ninth Conference on **Communicating Astronomy with the Public** was organised virtually during May 24 – 27, 2021. Held over different time zones to accommodate participants from around the globe, the conference attracted about 1,346 registrations from 87 countries. Sonal Thorve, Atharva Pathak, Shivani Pethe presented work on different projects of IUCAA SciPOP. Samir Dhurde along with Arvind Paranjapye (Nehru Planetarium, Mumbai), and Sonal Thorve conducted a workshop on Zero Shadow Day as well.

Public Engagement in Astronomy in the Pandemic Era.

This conference was held by the Indian Institute of Astrophysics from 2 - 4 August 2021. Samir Dhurde gave an invited talk on the topic "**Reaching out while staying distanced: some positive ideas**" and also chaired the session on "**Using media in novel ways**". Shivani Pethe and Atharva Pathak delivered a combined talk on the "**Use of Apps and Video series for effective Astronomy Outreach and Pro-Am Engagement**". Sonal Thorve presented on "**Stimulating Individual and Vernacular Engagement by Utilizing Online Tools**". In this, they shared various events organised by IUCAA SciPOP as well as shared the experiences and the footsteps of how they were executed.

Global Hands-on Universe Conference (GHOU-2021)- 23 to 27th August 2021

This year **GHOU 21 conference was held virtually from 23 to 27th August 2021.** A workshop for educators across the globe on "**Zero Shadow Day for Tropical countries**" was conducted by Samir Dhurde and Sonal Thorve from IUCAA SciPOP along with Alok Mangaogane at the Global Hands-On Universe Conference 2021 (virtual). In the workshop, Samir Dhurde shared the details of the zero shadow day and how it occurs. Alok Mandaogane explained the features and use of relevant android apps and websites. Sonal Thorve demonstrated how shadows are formed and how one can use them to track the Sun in the sky.

Rupesh Labade delivered an oral presentation on the topic of Bringing Astronomy to the students and teachers using "Appstronomy" and also took an online workshop on the topic of Learning Science at home during the lockdown.

The IAU Offices Family Meeting

Held online from the 20th to the 22nd of July 2021, bringing together the global networks of the four IAU Offices. The meeting had 30+ sessions on astronomy education, teaching, outreach, equity, and more. Samir Dhurde participated in this as the IAU National Outreach Coordinator, India and moderated two sessions on the themes - "**Research in classrooms**" and "**Astronomy education in low-income communities**".

WEBINARS AND TALKS

The following lectures were organised as a part of the Basic Course in Practical Astronomy organised by Jyotirvidya Parisanstha, Pune.

*December 03 – Samir Dhurde delivered a talk on "**Multiwavelength Astronomy**".*

*December 04 – Dr Surhud More delivered a talk on "**Difference imaging for Astronomical discovery of transients**".*

*December 05 – Bhushan Joshi delivered a talk on "**Advanced instrumentation**".*

*December 08 – Prof. Somak Raychaudhury delivered a talk on "**Cosmology**".*

*December 09 – Prof. Ajit Kembhavi delivered a talk on "**White dwarfs and neutron stars**".*

Astronomy webinars on different topics were organised by different institutes with SciPOP resource persons as guest speakers.

*October 08 – Sonal Thorve delivered a talk on "**Talk on Nobel Prize Physics 2020**" at MSS Highschool, Chinchwad.*

*October 09 – Samir Dhurde delivered a talk on "**History of Telescopes**" at Kaylan Pradeshik Lok Vigyan Kendra, Bhavnagar, Gujarat as a part of World Space Week celebrations.*

*October 10 – Tushar Purohit delivered a talk on "**Observing Meteor Shower**" at Smart Circuits Innovation, Chandigarh as a part of World Space Week celebrations.*

*December 17 – Samir Dhurde delivered a talk on "**Try out Planetary Science yourself**" at Nehru Science Centre, Mumbai.*

November 01 – Chasing Shadows: Citizen Science opportunities in occultation recording, by Ted Blank, Senior Member of IOTA (International Occultation Timing Association)

*December 06 – **Research the Solar System with Shooting Stars**, by Karl Antier, IMO (International Meteor Organisation)*

*December 06 – **Recording Meteor Showers - Live simulations and training**, by Arvind Paranjpye, Director, Nehru Planetarium, Mumbai*

*December 13 – **Tonight's Geminids and other meteor showers over India**, by Peter Jenniskens, Principal Investigator of the Cameras for All Sky Meteor Surveillance(CAMS) project of SETI Institute, NASA*

30th July, 2021 - "**The World of Large Telescopes**" by Samir Dhurde for the Department of Physics, Gauhati University, coordinated by IUCAA Associate Dr Sanjeev Kalita.

15th September 2021 - Talk by Rupesh Labade on Magnetism at Rani Laxmibai Saniki Mulinchi Shala, Pirangut for the 250 Students of 8th and 9th Standard.

17 September 2021 - "**Introduction to Astronomy and Astrophysics**" with talks by Samir Dhurde and Ranjan Gupta for the Physics department, St. Joseph College, Jakhama, Nagaland.

Demonstrations:

Amruteshwar Arts, science, commerce college, Wizer - by Rupesh Labde on 8th September 2021 Nearly 200 students from Junior college attended this Science Toys demonstration.

Abeda Inamdar Girls College, Pune - held virtually by Rupesh Labade on 23rd September 2021 A total of 400 students of 12th Standard and 6 teachers attended this Science Toys session.

Sacred Heart School, Kalyan - online Science Toys demo by Rupesh Labade on 27th September 2021 for the 120 students of 9th grade.

Tirupati Highschool, Satara - by Rupesh Labade on 30th September 2021. 200 students from 5th to 10th Standard attended this session online, covering the topic Use of Mobile Apps for sky observation.

LIEPO ACTIVITIES

SOCIAL MEDIA INVOLVEMENT

A variety of new engaging articles were published in the Gravity Matters blog on the LIGO-India website at www.ligo-india.in/gravitymatters/. under different sections of the *Gravity Matters* blog. Some of the highlights include **podcasts by distinguished gravitational wave personalities** like Prof. Sanjeev Dhurandhar and Prof. Tarun Souradeep, *SciArt* posters for the NSBH discovery, various **GW science articles** from GW scientists from across the world, ***Behind-the-Scenes* interviews** with GW researchers and students.

In the "Behind the Scenes" category which delves into the daily lives of gravitational-wave science researchers, LIEPO published a video interview of Dr Nikhil Sarin - a postdoctoral fellow from Monash University working on various aspects of gravitational-wave multi-messenger astronomy. Along with the webpage, it was also posted on LIEPO's YouTube channel and has been viewed more than 330 times to date. The 8th episode of the **"Listening to the Cosmos"** podcast series, which features international speakers talking about GW Science, was published. This episode presented Prof. Anna Watts (Professor of Astrophysics at the University of Amsterdam), winner of the AAS HEAD (High Energy Astrophysics Division) mid-career prize in conversation with Debarati Chatterjee (Chairperson of LIEPO and creator/ coordinator of the Gravity Matters blog).

TALKS AND WEBINARS

Live talk "Dawn of Multimessenger Astronomy!" by Prof. Parameswaran Ajith - GW170817 anniversary celebrations

LIGO-India EPO organised a live talk by Prof. Parameswaran Ajith from ICTS Bangalore on 17th August 2021 to commemorate the anniversary of GW170817 - the first observation of gravitational waves from the collision of two neutron stars by the LIGO and Virgo gravitational-wave detectors. The talk targeted both the general public and graduate/ postgraduate students and covered what this rare astronomy event has taught us and how it was not only detected in gravitational waves but also seen in light by dozens of telescopes on the ground and in space thereby giving rise to the new domain of Multi-messenger Astronomy. In the end, the viewers had the opportunity to ask questions, many of which were answered by Prof. Ajith. The event was coordinated by Prof. Debarati Chatterjee and executed by Vaibhav Savant.

Webinar on "First Five Years of Gravitational-wave Astronomy" by Prof. Archana Pai for World Space Week - 9th October 2021

A webinar on the "First Five Years of Gravitational-wave Astronomy" was presented live by Prof. Archana Pai (Associate Professor, IIT-Bombay) as part of the World Space Week on 9th October 2021. This was organised by the Mumbai Chapter of the National Space Society Pai spoke about the exciting research and findings from the first direct detection of gravitational waves from an Intermediate Mass Black Hole (IMBH) to the recently detected gravitational-wave event nicknamed GW190521. The event was held online on the Zoom platform for undergraduate and postgraduate students of Engineering and Pure Science backgrounds. Around 150 students participated in the webinar. Ankit Bhandari assisted in setting up the webinar.

Astropix Online Astrophotography Webinar series and Contest - 15th November to 15th December 2021

Astropix, a webinar series specialising in astrophotography, was organised by LIGO-India EPO to inspire budding astrophotographers and astronomy enthusiasts. A set of five webinar sessions were conducted by experts between 15th Nov - 15th Dec 2021. The webinars covered a range of topics from the basics of astrophotography and photography, essential equipment to advanced skills, to post-processing using free software. The session also comprehensively explored the various aspects that go into planning a successful astrophotography shoot. Several free-to-use PC, smartphones and web-based apps and services were recommended to help in planning the shoot. One session was also conducted in Hindi for the benefit of the participants. The Q&A sessions after the webinars saw enthusiastic interaction from participants who were delighted at the opportunity to get expert advice. The sessions were attended by more than 150 participants on Zoom and the recordings on LIEPO's YouTube Channel have around 1000 views to date. An astrophotography competition was announced after the last webinar to encourage participants and viewers to take up this fascinating hobby. The competition is currently open and collecting entries from 15th December 2021 to 15th January 2022. This activity was coordinated by Prof. Debarati Chatterjee (Professor at IUCAA and Chairperson of LIEPO) with assistance and technical support from Vaibhav Savant (LIEPO Coordinator at IUCAA) and GWSCP participants.

CONFERENCES

LIMMA conference videos

As part of the same anniversary celebrations, a video of Prof. Abhay Ashtekar with Prof. Martin Hendry was released on 15th September 2021. In this, the speakers discuss the **future of gravitational-wave astronomy in India.** This was the first of a series of videos shot during the **The "Multi-messenger Astronomy in the Era of LIGO-India (**LIMMA) conference in 2019, where the world's leading experts on gravitational wave detectors had gathered to discuss the new physics and astrophysics they may unravel in the era of LIGO-India.

LIMMA video - Peter in conversation with Varun - 6th October 2021

(LIMMA) conference was held from 15th-18th January 2019 at Khandala. LIEPO organised and recorded interviews of GW experts from around the world who were present here. The LIMMA video featuring Prof. Peter Shawhan (Associate Professor and Associate Chair for Graduate Education at the University of Maryland) with Prof. Varun Bhalerao (Associate Professor at IIT-Bombay) was released on 6th October 2021. In this video we hear about Prof. Peter Shawhan's journey into the world of gravitational waves, starting with the early days of the LIGO detectors in 1990 and the various skill sets required for working at advanced gravitational-wave detectors such as LIGO. The video was released on LIGO-India EPO's YouTube channel which has more than 6200 subscribers as of now.

PRESS RELEASE

Press Release for LVK All Sky All Frequency paper - 20th October 2021

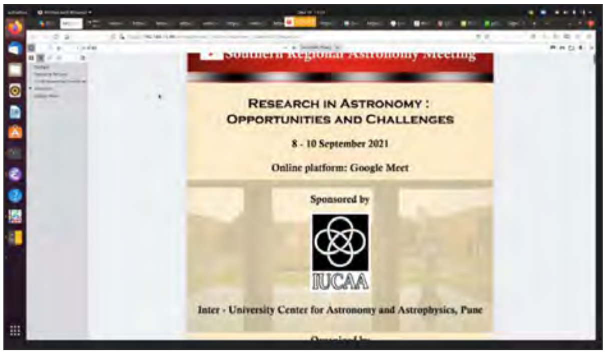
The LIGO-India EPO team facilitated the press release in India for the latest paper submitted to arXiv by the LIGO Scientific Collaboration, the Virgo Collaboration and the KAGRA Collaboration on the "**All-sky, all-frequency directional search for persistent gravitational waves from Advanced LIGO's and Advanced Virgo's first three observing runs - O1, O2 and O3"**. A team of gravitational-wave researchers from IUCAA have consistently been contributing to this topic. The press release highlighted the contributions of these and other LIGO-India Scientific Collaboration members towards this study. A simplified summary of the paper was shared with press contacts and also circulated on LIGO-India EPO's social media channels - Facebook, Instagram and Twitter to share the excitement with gravitational-wave enthusiasts.

BOOK LAUNCH

"Listen to the Universe" children's book launch on GW discovery anniversary

An illustrated children's pop-up book in Marathi - **"Aika Brahmand Kay Mhante" (Listen to the Universe)** was launched on the occasion of the anniversary of the first direct detection of gravitational waves by LIGO. This book was written by LIGO-India's colleagues from the University of Glasgow, IUCAA SciPOP in collaboration with LIGO-India EPO and is supported partly by the Newton Bhabha Fund. The book has initially been published in Marathi, the native language of school children in the vicinity of the LIGO-India observatory site in Maharashtra. The book reading videos were premiered on LIGO-India EPO's YouTube channel on 14th September 2021, in three languages, including Marathi, English as well as Hindi, in the spirit of the Hindi Divas which was also celebrated on the same day.

RESEARCH IN ASTRONOMY: OPPORTUNITIES AND CHALLENGES



Seventh Southern Regional Meeting
September 8-10, 2021

The Department of Physics, Mar Thoma College, Chungathara and the Providence Women's College, Calicut conducted the Regional Astronomy Meeting for the Southern region of India, in association with IUCAA, during September 8 - 10, 2021. The purpose of the meeting was to help the researchers of the region in updating themselves with the latest developments in the field and in identifying new research areas and problems. This was also envisaged to serve as a platform for interacting with scientists from the field and for fostering further teamwork and collaborations. Due to the pandemic Covid-19, we used the online medium for the meeting.

The meeting was inaugurated by Somak Raychaudhury, Director, Inter-University Centre for Astronomy and Astrophysics, Pune and felicitated by Kandaswamy Subramanian, Dean, IUCAA. The plenary lectures on the theme of Future Astronomy in India was delivered in the mornings by Bala Iyer (ICTS, Bengaluru), Shyama Narendranath (ISAC, Bengaluru) and Ajit Parameswaran (ICTS, Bengaluru). Due to the enhanced response to the meeting, the sessions were arranged in parallel. During these three days of the meeting, we had presentations from research scholars interspersed with the overview talks by senior researchers, spread into eight sessions. The meeting discussed the areas of research including Cosmology, Stellar Astrophysics, X-ray Astronomy, Extragalactic Astronomy, ISM and galactic astronomy and Radio Astronomy. There were a few presentations by Post Graduate students on the curricular projects they did in the field of Astrophysics. Altogether there were three plenary Lectures, 5 Special review talks, 14 invited review talks, 35 contributed talks and 11 UG/ PG presentations. The special talks on the seminal work from the region which attracted media attention were arranged every day in the morning session, just after the plenary lectures. To compensate for the usual discussions and interactions which used to happen in the 'physical' meetings, two interaction sessions were also arranged in the evenings of September 8th and 9th. This year, the consolidated abstract book, including all abstracts of the talks in the meeting, was released on the third day of the workshop. The workshop was coordinated by Sheelu Abraham (Mar Thoma College, Chungathara), Jeena K (Providence Women's College, College in Kozhikode) and Ranjeev Misra (IUCAA).

IUCAA-NCRA GRADUATE SCHOOL

PH. D. PROGRAMMME

During the year of this report, ten IUCAA Research Scholars namely: **Debabrata Adak** [Guide: Tarun Souradeep], **Suman Bala** [Guide: Dipankar Bhattacharya], **Yash Bhargava** [Dipanakar Bhattacharya], **Bhaskar Biswas** [Guide: Sukanta Bose], **Sayak Dutta** [Guide: Sukanta Bose], **Shalabh Gautam** [Guide: Sukanta Bose], **Soumak Maitra** [Guide: R. Srianand], **Swagat Mishra** [Guide: Varun Sahni], **Gitika Shukla** [Guide: R. Srianand], **R. Sujatha** [Aseem Paranjape] have defended their Ph.D. theses. Their Ph.D. degrees have been awarded by the Jawaharlal Nehru University, New Delhi. The synopses of their theses are given below :

Debabrata Adak

Foreground challenge in the quest for primordial B-modes in CMB polarization

Potential detection of the primordial B-mode polarization in Cosmic Microwave Background (CMB) is one of the major challenges to the cosmologists in the next decades. The primordial B-modes in CMB are generated from the primordial Gravitational waves, one of the key predictions of the inflation theory. Inflationary models generically predict the generation of B-mode signal in CMB. The amplitude of the signal, parameterised by the tensor-to-scalar ratio r, depends on the energy scale of the inflation, and hence, lacks a strong theoretical lower bound. Measurements of CMB polarization data with increasingly high resolution and sensitivity are now becoming available, and even higher quality data are expected from the ongoing and future experiments. However, this B-mode signal can be tiny and is highly obscured by our Galactic diffuse emissions, e.g., thermal dust, synchrotron, spinning dust and extragalactic sources, collectively referred to as CMB foregrounds for B-mode search. The level of foreground contamination depends on the frequency and sky patch of the observations. Future balloon-borne, space-based and ground-based experiments are targeting to detect B-mode for $r \sim 10^{-3}$. This tiny signal is obscured by dust and synchrotron by order of magnitudes respectively at high and low frequencies. The spinning dust and extragalactic sources have low polarization fractions and may impact r measurement. Therefore, the foreground is the key challenge to detect B-modes from primordial Gravitational waves. Building only high sensitive bolometers to measure this polarization pattern in CMB will not help us. Significant advancements in data analysis techniques are also required. Most importantly, polarized foregrounds should be characterised accurately and must be subtracted precisely from CMB. Therefore, we need to develop accurate foreground models and new efficient component separation algorithms for potential detection of the primordial B-modes.

This thesis presents a set of works covering different aspects of research that would enable this important research quest. This thesis focuses on three aspects: modelling and characterising dust, developing component separation algorithm, and assessing the bias of foreground residuals in cleaned CMB maps on the measurement of primordial B-mode for future CMB missions.

Galactic dust is one of the major contaminants for B-mode search. Therefore, a substantial part of this thesis is devoted to building a statistical dust polarization model at 353 GHz and characterising the dust spectral properties. Dust and synchrotron polarization maps at different frequencies are important in the context of foreground studies as well as the study of Galactic astrophysics. These maps can be estimated from multi-frequency observations at microwave bands. We develop a novel semi-blind component separation method. We demonstrate the performance of this algorithm to extract thermal dust and synchrotron from multi-frequency WMAP and Planck simulated data. Finally, we forecast the impact of foreground residuals present in the foreground minimised CMB map on the detection of tensor-to-scalar ratio. Our forecast analysis is done for instrument design of 'CMB-Bharat', a proposal for next generation CMB space mission submitted to Indian Space Research Organisation (ISRO).We present the performance of the Bayesian component separation algorithm COMMANDER for cleaning the CMB from foregrounds for this instrument design. We assess the residual bias on r measurement for various simulations that include diffuse foreground models of varying complexity and detection sensitivity in the presence of primordial B-modes.

The algorithms and modelling framework developed and results obtained in this thesis are expected to be essential for the ongoing efforts to detect the primordial B-modes using future high sensitive CMB observations. Our forecast results of r measurement will be helpful to the 'CMB-Bharat' collaboration on improving its instrument design as the mission will mature. The forecast results also motivate developing more robust component separation techniques to handle foreground complexities. are expected to be useful to extract the Galactic emissions for the study of Galactic science.

Suman Bala

Study of The Magnetic Fields of Neutron Stars Through Cyclotron Resonance Scattering Features.

Neutron stars are extremely compact objects with 1-2 solar mass ($M_{\odot}$) of material condensed within $\sim$ 10 Km radius. They possess strong surface magnetic field ($\sim 10^{12}$ G) and are known to function as radio pulsars, or as accreting X-ray pulsars when they attract material from nearby stellar companions. The infalling matter is channeled to the magnetic poles of the neutron star by the magnetic field lines. Cyclotron Resonance Scattering Features (CRSFs) are produced by resonant scattering of photons off electrons moving perpendicular to the magnetic field and they are strongly dependent on the local field strength. The emission region of X-ray spectra, showing cyclotron lines, is thought to be located at or near the magnetic polar cap of accreting X-ray pulsars. One can probe the structure and evolution of the magnetic field in the x-ray emission region of neutron stars through a detailed study of CRSFs, which forms the main theme of this thesis.

This thesis explores different properties of the observed cyclotron lines, using data from different satellites, like ASTROSAT, SUZAKU, NuSTAR, XMM-Newton etc. This thesis is presented in 8 chapters. Chapter 1 provides a general introduction and chapter 2 describes the instruments that have been used to gather the data utilized in this thesis. The work presented in the remaining chapters is outlined below.

Some of the data used in this thesis have been obtained using the Large Area X-ray Proportional Counter (LAXPC) instrument on board the Indian Space Astronomy Mission ASTROSAT. In the Normal Course of Analysis, a large systematic error is usually included while fitting the LAXPC spectrum. Such high systematic errors make it very challenging to find or/and constrain the presence of any cyclotron lines which are often detected as weak absorption like features against the X-ray continuum. Chapter 3 presents our attempt to mitigate this effect by creating an empirical Auxiliary Response File (ARF) that models the residuals present in the Crab spectrum. We found a major reduction in the systematic error required to obtain acceptable spectral fits after the inclusion of the ARF.

Chapter 4 of this thesis reports a spectral and timing study of the High Mass X-ray Binary (HMXB) source 4U 1700-37, using NuSTAR and ASBTROSAT/LAXPC. The source is observed in two different flux states. The spectral analysis of NuSTAR data shows the possible hint of a cyclotron line feature, which suggests that the compact object is a neutron star and we can estimate the magnetic field strength in the emission region. The shape of the cyclotron line is found to be dependent on the model of the continuum used. With some continuum models the line is found to have a double peaked structure which can be better described as a combination of two features with anharmonic ratio or a distorted line. This study also finds the presence of a rare Ni $K\alpha$ emission in the NuSTAR spectrum. A weak hint of the same is found in the low flux XMM-Newton data, whereas, in SUZAKU/XIS data the line is very prominent. In timing analysis, no coherent or quasi-periodic oscillation signal could be found in the LAXPC and NuSTAR data.

In chapter 5, analysis of the LAXPC data of the high mass x-ray binary GX 301-2 is presented. The source GX 301-2 is well known to exhibit a prominent cyclotron line, which changes its energy with the spin phase. We detect a Gaussian cyclotron absorption line, and the line is found to be present at the same energy for different continuum models. We have also attempted a spin-phase resolved spectroscopy. We find that the continuum model is quite same across all phases, but due to low counts in the phase resolved spectra we are not able to adequately constrain model parameters. The cyclotron line is present in all phases with the line energy showing a slight variation, but within the error margin of the estimates. Reduction of systematic uncertainties and improved estimate of the background are required to better constrain the model parameters. We have also found a prominent presence of an iron K_α line in this source.

The cyclotron line feature in the X-ray spectrum of the accretion powered pulsar Her X-1 has been observed and monitored for over three decades. The line energy exhibited a slow secular decline over the period 1995-2014, with a possible indication of a reversal thereafter. Recent works have shown that the temporal evolution of the line energy may be modelled as a flattening after an earlier decrease until MJD 55400 ($\pm$200). Chapter 6 presents the results of ASTROSAT observations in the context of earlier data and offers a common interpretation through a detailed study of temporal and flux dependence. It is concluded that the variation of the line energy does not support an upward trend but is consistent with the reported flattening after an earlier decrease until MJD 54487^{+515}_{-469}.

Chapter 7 presents a theoretical framework for predicting cyclotron line shapes, assuming the presence of an accretion mound at the polar cap of the neutron star. It is considered that the accretion mound is in a steady state equilibrium supported by the magnetic field. The mound is assumed to be axisymmetric and its dynamics to be governed by ideal MHD equations. The structure of the mound in magnetostatic equilibrium is solved numerically to obtain the matter density configuration and the magnetic field distribution. From this, the local magnetic field at the mound surface is computed, which is then used to generate the profile of the expected cyclotron lines. This is done for a range of mound masses and magnetic field strengths, all the computed profiles are then cast in the form of a Table Model to be used for spectral fitting using the XSPEC software package. We have attempted fitting this model to explain the observed anharmonic ratio between the observed cyclotron line energies of Cep X-4. We find that the observed feature in Cep X-4 can be explain as the presence of two harmonics which are affected by the magnetic field distortion caused by the accretion mound.

To generate a more detailed prediction of CRSF profiles, we have used a Monte-Carlo radiative transfer code. This code accepts an input continuum and performs the line transfer by including the three cyclotron resonant processes (absorption, emission and scattering). Subsequently, the effects of gravitational red-shift and light bending on the emergent spectra are applied. The code has been used to predict the observable spectra from three different emission geometries; 1) an optically thin slab near the stellar surface, 2) an accretion mound formed by the accumulation of the accreted matter, 3) an accretion column representing the zone of a settling flow onto the star.

Chapter 8 summarizes the main conclusions of the thesis. The chapter also outlines a few possible directions of future work.

Yash Bhargava

Spectro-timing study of Accretion Disks

Black hole binaries are one of the brightest sources in the X-ray sky. Most of the discovered black hole binaries are transient in nature and are detected when they undergo an outburst. Observing these sources in soft and hard X-rays provides a unique view into the processes in the vicinity of the black hole. The X-ray emission from these systems is typically comprised of two components, the photons from a thermalised accretion disk and a comptonised radiation from a hot thermal cloud of electrons. As the source goes through an outburst, the relative contribution of these two components vary, resulting in a plethora of spectral and temporal features which can be used to study these sources. Most of the sources often show hysteresis in their hardness-intensity diagram, highlighting the complex accretion dynamics in these sources. The positions of the source on the hardness-intensity diagram correspond to its different spectral states.

The hard state of black hole binaries is particularly interesting as the emission during the hard state is dominated by the comptonisation of the disk photons intercepted by the thermal electrons. The accretion disk is typically truncated at the inner edge. The comptonised emission further interacts with the disk and produces reflection features (i.e. fluorescent Fe Kα emission line and compton hump). The hard state is also typically more variable than the soft state which is dominated by the emission from the thermalised disk. The variability in the hard state is characterised by a broadband noise spanning more than two decades in the Fourier frequency with occasional presence of peaked features which are referred to as Quasi Periodic Oscillations (QPOs). The soft state of the source has a thermalised disk which extends up to the Innermost Stable Circular Orbit (ISCO). Thus measurement of the inner radius of the accretion disk in the soft state allows to place a constraint on the spin of the black hole.

Some of the key fascinating problems in understanding of the black hole binaries are: a) Intrinsic parameters of the black hole and their effect on the dynamics of the accretion disk, b) Origin of different variability features, mainly QPOs, and the relation between the these temporal features and the emission from these sources, c) Geometry of the accretion disk and comptonising cloud in a black hole binary.

This thesis delves into different aspects of accretion around stellar mass black holes by investigating various spectral and temporal properties of these systems. Chapter 1 gives a preliminary introduction to the black hole binaries, discusses the different models of accretion and describes some of the open questions which are addressed in this thesis. Chapter 2 gives a brief overview of the instruments used to study these enigmatic sources. The thesis is divided into two parts: Part I (comprising of Chapters 3, 4 and 5) discusses aspects of fast variability from short to long time-scales while Part II (consisting of Chapters 6 and 7) discusses evolution of spectral properties at long timescales. Chapter 8 summarises the work done for the thesis and outlines follow-up projects.

Extensive monitoring of black hole transients using high-time resolution instruments provides a unique opportunity to study the evolution of the fast variability in these systems. MAXI J1820+070 is one of the brightest black hole binaries in the recent times to have undergone an outburst. The source was monitored almost daily by *NICER* for the duration of its outburst. Using this extensive monitoring, we track the variation of the QPO observed in the source. By interpreting the QPO and the associated broad noise features as frequencies from the Relativistic Precession Model, we obtain tight constraints on the spin of the black hole. The method is a complementary technique to spin measurements from spectroscopy and can provide independent verification of the elusive spin parameter. The details of our studies pertaining to this project are described in Chapter 3.

Chapter 4 tracks the evolution of the QPO observed in MAXI J1535−571 along with spectral parameters. In a single long observation of the source using *AstroSat*, the QPO frequency was observed to fluctuate within 1.8–3.0 Hz with the flux of the source continually rising. The spectral slope of the source, parameterised by the powerlaw index, indicated a fluctuation similar to the QPO frequency. The observation proves the association of the QPO with the compotonising medium which is responsible for producing the powerlaw emission. The fluctuations were also seen to be weakly correlated with the variations in flux after subtraction of a linear trend arising from increasing accretion rate. This indicates that the fluctuating comptonising medium which is responsible for the QPO.

The variability in the black hole binaries is not limited to the QPOs but it also manifests as broad band noise features in the power density spectra. One of the prominent black hole binaries, Cygnus X-1, shows aperiodic peaking features, also known as 'shots', which typically describe the low frequency variability. Chapter 5 describes a study in which using a simultaneous *AstroSat-NICER* observation of Cygnus X-1, we have detected exact simultaneous shots in the lightcurves. The shot profile was divided into 9 phases and the shot-phase resolved spectrum of the source was investigated to identify the varying components during the shot. We find that during the shot, the accretion rate of the source is consistent with a constant while the inner radius of the disk moves inwards and outwards in the time scale of a few seconds. The inward/outward motion of the inner edge of the disk is accompanied by an increase/decrease in the fraction of the upscattered photons and an increase/decrease in the spectral slope. The shot phenomenon Cygnus X-1 is thus interpreted as inward and outward motion of the inner edge of accretion disk at constant accretion rate which causes a corresponding change in the compton upscattering of the disk photons and subsequent effect on the powerlaw index of the comptonising region.

At a longer timescale, the variation in the spectrum is typically dominated by either physical changes in and around the source or simply geometrical effects. An interesting example of the latter is Cygnus X-3 which shows a prominent orbital modulation in X-rays. The modulation also affects the spectrum at different orbital phases. Chapter 6 reports the results from our studies of the spectral variation of Cygnus X-3 in its Very High State using *NuSTAR* observations as a function of time (and orbital phase). We find that a significant variation in absorption column density is observed as a function of the orbital phase indicating that the absorbing material is tidally locked to the binary system. Across different observations, the properties of the additional absorbing material are observed to be similar. The line energy of relativistically broadened iron emission line also shows a significant variation with the orbital phase indicating an orbital dependence of the reflection features.

The reflection of X-rays originating from the comptonising medium off the disk is a well-observed phenomenon. With the current high sensitivity detectors, it is possible to constrain the geometry of many sources by characterising the reflection spectrum. The dependence of the reflection fraction on the inner truncation radius favours a lamp-post geometry of the comptonising medium while the converse indicates that the comptonising medium has a sandwich-like geometry in which the medium covers a part of the accretion disk. A subset of black hole binaries has shown weak or no reflection which makes them highly interesting targets for understanding different manifestations of the accretion geometry. In the study described in the Chapter 7, a sample of three such sources (MAXI J1727-203, Swift J1357.2-0933 and Swift J1753.5-0127) monitored by *NuSTAR* at different epochs of their respective outbursts is studied. Using the high sensitivity of *NuSTAR* in the energy range appropriate for a study of reflection, we are able to place strong constraints on the lack of reflection in these sources. All the observations except one analysed in this study were taken in hard state. The hard state observations of these sources can be explained adequately with an absorbed powerlaw. The soft state observation of Swift J1753.5-0127 indicated a highly truncated disk. We investigate possible reasons for the low reflection fractions, including the hypothesis that varying levels of disk truncation is a primary determinant of reflection fraction.

Bhaskar Biswas

Constraining the equation of state of neutron stars using multimessenger observations

Neutron stars are the densest objects known in our universe. Properties of matter inside neutron star are encoded in its equation of state, which has wide-ranging uncertainty from the theoretical perspective. With the current understanding of quantum chromodynamics, it is very hard to determine the interactions of neutron star matter at such high densities and also performing many body calculation is computationally intractable. Besides the constituent of neutron star at its core is highly speculative – perhaps containing exotic matter like strange baryons, meson condensates, quark matter, etc. We cannot produce such dense material in our laboratory. Since probing the physics of NS matter is inaccessible by our earth based experiments, we look for astrophysical observations of neutron star. This thesis deals with the theoretical and computational techniques to translate neutron star observable from astrophysical observations into the equation of state of neutron star.

With the first detection of gravitational wave from a binary neutron star merger event GW170817 along with its electromagnetic counterpart, we have now entered into multimessenger astronomy of neutron star. Novel constraint on the neutron star equation of state can be obtained from the inspiral phase of the signal as it carries the imprint of neutron star matter due to the tidally deformed structure of the components. Because of extreme nature, there are several physical processes inside the neutron star which might be present such as anisotropic pressure and presence of solid crust. Generally, in the standard theoretical formulation of an equilibrium or perturbed relativistic star, we do not include those effects. One of the primary aim of this thesis is to examine the effect of these effects on the neutron star observable and see whether it is possible to discern the presence or absence of those processes.

We are now in a golden era of neutron star physics. Not only gravitational wave observation, recently NICER collaboration has also provided a very accurate measurement of mass and radius of PSR J0030+0451 by observing X-ray emission from several hot spots of neutron star surface. By combining these observations coming from multiple messenger we could provide a stringent constraint on neutron star properties. The major part of this thesis focuses on constraining neutron star equation of state combining multiple observations using Bayesian statistical formalism based on a hybrid equation of state formulation that employs a parabolic expansion-based nuclear empirical parameterization around the nuclear saturation density augmented by a generic 3-segment piecewise polytrope model at higher densities. Finally, this hybrid equation of state formulation is used to study the nature of the "mass-gap" object in an gravitational wave event named GW190814, deteceted by LIGO/Virgo collaboration.

Sayak Dutta

Distinguishing black holes, neutron stars and exotic compact objects in inspiraling binaries

The primary defining feature of a classical black hole is being a perfect absorber. Any evidence showing otherwise would imply a departure from the standard black-hole picture. Energy and angular momentum absorption by the horizon of a black hole is responsible for tidal heating in a binary. This effect is important in the late stages of an extreme mass ratio inspiral around a spinning supermassive object, which is one of the main targets of the upcoming LISA mission. We study the potential of this effect to be used as a probe of the nature of supermassive objects. We compute the orbital dephasing and the gravitational-wave signal emitted by a point particle in circular, equatorial motion around a spinning supermassive object to the leading order in the mass ratio. The absence of absorption by the central object can affect the gravitational-wave signal dramatically, especially at high spin. This effect will make it possible to put an unparalleled upper bound on the reflectivity of exotic compact objects, at the level of $\mathcal{O}(0.01)\%$. This stringent bound would exclude the possibility of observing echoes in the ringdown of a supermassive binary merger. We also do a Fisher analysis to estimate the errors that will be present for EMRIs.

We study how tidal heating of an ECO gets modified due to the presence of a reflective surface and what implication it brings for the gravitational wave observations. We argue that the position of the reflective surface, $\varepsilon \gtrsim 10^{-5}$, can have an observational impact in extreme mass ratio inspirals. We also discuss a possible degeneracy between ε and reflectivity, $|\mathcal{R}|^2$, in the context of parameter estimation.

In the context of comparable mass binaries, we show how by careful monitoring of the presence or absence of tidal deformability (TD) and tidal-heating (TH) in the inspiral signal of compact object binaries in ground-based gravitational-wave (GW) detectors one can test if its components are black holes or not. The former property (TD) is finite for neutron stars but vanishes for black holes (in General Relativity), whereas the latter is finite for black holes and negligible for neutron stars, and affects the GW phase evolution of binaries in a distinctly different way. We introduce waveform parameters that characterize the strength of tidal heating and are zero when there is no horizon. We demonstrate how by using those parameters Bayesian methods can distinguish the presence or absence of horizons in a binary. This is a particularly exciting prospect owing to several claims that these stellar-mass objects, especially, with masses heavier than those of neutron stars, may not have a horizon but may be black hole mimickers or exotic compact objects (ECOs). Perhaps more significant is the possibility that our method can be used to test the presence or absence of horizons in mass-gap binaries and, thereby, help detect the heaviest neutron star or the lightest black hole. A proper accounting of tidal-heating in binary waveform models will also be critical for an unbiased measurement of characteristics of the equation of state of neutron stars in GW observations of binaries containing them – or even to probe the existence of ECOs.

Shalabh Gautam

Towards Einstein Field Equations in Spherical Symmetry on Hyperboloidal Slices: A Generalized Harmonic Gauge Formalism

To study explicitly the development of a large class of initial data (ID) through the Einstein field equations (EFEs) and predict the results quantitatively, we need to study it numerically. One needs access to future-null infinity, $\mathscr{I}^+$, to study this evolution and extract the resulting gravitational waves (GW) signal accurately. In this work, we aim at including $\mathscr{I}^+$ in the computational domain with a well-posed formalism. This goal requires addressing the problem at the level of geometry, partial differential equation (PDE) analysis and numerical techniques. The geometrical aspect of this problem is solved by using hyperboloidal slices, as explained in Chapters 1 and 2. From the PDE point of view, this problem is given a well-posed formulation by working in generalized harmonic gauge (GHG). The resulting equations are then adapted to hyperboloidal slices by using the Dual-Foliation (DF) formalism. All this is done in Chapter 3. Asymptotic analysis of the EFEs in GHG tells us that these equations can be categorized according to their fall off towards future null infinity. In Chapter 4, model equations, one from each of the identified classes, are considered, and a prescription is given to regularize them on hyperboloidal slices. This regularization scheme is then tested numerically, and consistent results are observed. The numerical aspects of the problem are dealt with by developing the summation-by-parts (SBP) scheme on these slices. Our derivations are performed for second-order accurate finite difference operators, but their extension to higher-order accuracy could be achieved straightforwardly. The origin is regularized, and suitable dissipation operators are also derived. Numerical experiments show dramatic improvement in the results in terms of numerical errors, long time convergence and stability. All these numerical triumphs are achieved in Chapters 5 and 6. Finally, in Chapter 7, the EFEs in GHG are evolved on these slices. The numerical results show regularity and convergence at $\mathscr{I}^+$ and in the trivial L^2 norm. Possible extensions and applications of the work are discussed in Chapter 8, some of which may have a bearing on future observations in GW astronomy.

Soumak Maitra

Probing the astrophysical and cosmological aspects of Intergalactic Medium using Quasar spectra.

The Intergalactic Medium (IGM) is a primary reservoir of the baryonic content of the Universe. The baryonic density fluctuations in the IGM are known to follow dark matter density fluctuations at large scales and hence can be used as a cosmological probe for structure formation. At small scales, IGM primarily probes astrophysical processes associated with galaxies and the circumgalactic medium. Also at high-z, pressure broadening involved at such scales retain information about thermal history of the IGM and hence can be used as a probe of the cosmic reionization. The matter distribution in the IGM manifests itself observationally in the form of H I Lyα forest absorption in the spectra of distant quasars. The observational properties of these absorption are determined by the thermal and ionization state of the IGM along with the dark matter density distribution. Numerical simulations and analytical modelling of a warm photo-ioinized IGM in the framework of ΛCDM models successfully reproduce many observed properties of the Lyα forest absorption: the column density ($N_{\rm HI}$) distribution, the Doppler b-parameter distribution, the flux probability distribution function, power-spectrum of transmitted flux and the redshift evolution of absorption lines above a certain $N_{\rm HI}$ threshold. Through these models we can constrain the H I photoionization rate, mean IGM temperature and temperature density relationship over a large redshift range. The Lyα forest has also been used to study cosmic reionization and thermal history of the universe as well as impact of various feedback processes (such as SNe and AGN driven outflows) on the IGM that operate during the formation and evolution of galaxies over cosmic time. Besides understanding the astrophysical properties of IGM, Lyα forest spectra has been useful in constraining cosmological parameters and placing bounds on the mass of warm dark matter particles and neutrinos.

Clustering studies of Lyα forest is essential for understanding the matter distribution of IGM. Due to easy availability of larger number of of single quasar sightlines, they have been used widely to characterize the longitudinal (i.e. redshift space) two-point correlation function (or power-spectrum) along quasar sightlines. However, redshift space correlations (for pixel-based flux statistics) are primarily affected by thermal broadening effects in comparison to the pressure broadened 3D structures in IGM. For probing the thermal history of the IGM one needs to capture these pressure broadened 3D structures which can be done with transverse correlation. Despite quasar pairs being relatively sparse in number, people have been studying clustering in the transverse direction between adjacent sightlines (transverse correlation) of closely spaced projected quasar pairs or gravitationally lensed quasars.

While several studies involving two-point correlation (or power spectrum in fourier space) in Lyα forest have been carried out to study clustering properties of the IGM, the higher order statistics remain largely unexplored. The first higher order term, i.e, three-point correlation will be useful in probing non-gaussianity in the matter density distribution caused by non-linear gravitational evolution. While three-point clustering (using three-point correlation, or bispectrum in fourier space) has been studied largely using low-z galaxies and high-z quasars, Lyα forest as an observable would be able to probe the matter clustering at smaller scales and higher redshifts. In addition to constraining the second order quadratic bias in clustering, three-point statistics can also act as an independent tool along with the two-point statistics in constraining cosmological parameters as well as the physical state of IGM. It has also been pointed out that the three-point statistics is helpful in removing the degeneracy between different cosmological parameters like the bias and amplitude of matter power spectrum.

Frequently used pixel based computation of correlation function in Lyα forest using transmitted flux is largely affected by the complex non-linear relation between transmitted flux and matter density field. In case of three-point correlation in transmitted flux, the amplitude is largely dominated by this complex relation rather than the non-gaussianity in matter distribution itself. In an alternate approach in this thesis, we use a novel absorber-based approach (similar to what one uses for galaxy clustering studies) for performing higher order clustering studies. We show that Lyα absorption decomposed into Voigt profile components (called absorbers in this work) provide a straightforward way for estimating three-point correlation and studying it as a function of H I column density ($N_{\rm HI}$) and line-width parameter (b). In this thesis work, we study three-point clustering statistics in both redshift space as well as in transverse direction using high-resolution quasar spectra in conjugation with N-body hydrodynamical simulations. The organization of the thesis is as follows.

- In **Chapter 1** we provide basic introduction to IGM and motivate various issues addressed in this thesis.

- **In Chapter 2** of the thesis, we present measurements of the redshift space clustering of low-z ($z < 0.48$) Lyα absorbers using HST-COS data and report the first measurements of longitudinal three-point correlation. At low-z, the Lyα absorbers originate from large overdensities compared to the Lyα absorbers at high-z. While most of the low-z IGM is photoionized, frequent presence of Broad Lyα absorbers (BLAs; defined as Lyα absorbers having b-parameters, b> 40 kms^{-1}) and ionization modelling of high ionization absorbers (probed by Ne VIII and O VI absorption) suggest that some of low-z Lyα absorbers may also be collisionally ionized. We explored the $N_{\rm HI}$ and b dependence of the observed two-point and three-point correlation. We also study the connection between Lyα clustering and galaxy distribution. Additionally, we investigate the impact of peculiar velocities and feedback processes on the clustering signals with the help of hydrodynamical simulations.

- **In Chapter 3** of the thesis, we have measured the redshift space two-point and three-point correlation of Lyα absorbers and studied their redshift evolution over $1.7 < z < 3.5$ using one of the largest sample of 292 high-resolution quasar spectra from KECK/HIRES and VLT/UVES. We do find the clustering of the Lyα absorbers above a fixed $N_{\rm HI}$ threshold to evolve with redshift strongly. We show this strong redshift evolution of clustering is mainly dominated by the redshift evolution of baryon overdensity-$N_{\rm HI}$ relationship. As in the case of low-z IGM, both two- and three-point correlation are found to be strongly correlated with $N_{\rm HI}$. At high-z, where the Lyα typically originates from photo-ionized diffused gas and retains the thermal memory of the past, we studied the impact of the thermal history and the ionization state of the IGM on the observed Lyα clustering using simulations. The simulations obtained with UV ionizing background consistent with available measurements of H I photoionization rates, produce consistent clustering signals with observations at $z \sim 2$. However, they under-predict clustering at higher redshifts. We have also used simulations to investigate the effect of peculiar velocities and feedback processes.

- **In Chapter 4** of the thesis, we use N-body hydrodynamical GADGET-3 simulations to generate a statistically large number of mock quasar triplet sightlines and analyze the transverse three-point correlation over different cofigurations and transverse scale of 1-5 $h^{\;\;1}$ cMpc at $z \sim 2$. We find the three-point correlations to depend strongly on $N_{\rm HI}$ and linear scale and weakly on the angle of the triplet configuration. We show that the 'hierarchical ansatz' is applicable for scales $\geq 3h^{-1}$ cMpc, and obtain a median reduced three-point correlation (Q) to be in the range $0.2 - 0.7$. We show, the transverse three-point correlation is influenced strongly by the thermal and ionization state of the gas. We study the effect of pressure broadening on three-point correlation using a model with artificially boosted heating rates. While pressure smoothing effects are clearly seen in this case, for models with realistic thermal and ionization histories the effect of pressure broadening on three-point correlation is found to be subdominant compared to other local effects. We discuss the observational requirements for the detection of transverse three-point correlation, specifically, in small intervals of configuration parameters and redshift.

- **Chapter 5** of the thesis attempts at studying transverse clustering of Lyα forest ($2 \leq z \leq 2.5$) using X-Shooter spectra of three background quasar triplets probing transverse separations of 0.5–1.6 pMpc. We assign probabilities for realizing all the observed correlation properties simultaneously using our simulations. We also probe the matter distribution in 3D, possible only with such quasar triplets (or multiplets) and identify Damped Lyman-α systems (DLAs) along all three sightlines within a span of $\sim$ 37 pMpc along one of the triplets. Detection of a foreground quasar ($\sim$ 1 pMpc from the triplet sightlines) and excess partial Lyman Limit systems around these DLAs suggest that the sightlines may be probing a large overdense region. We also identified a concurrent gap of 17Å (i.e. $14.2h^{-1}$cMpc, one of the longest reported) wide along one of the triplets, which is most probably, representing a physical void. Using these sightlines, we also explore C IV-C IV auto-correlation as well as C IV-H I cross-correlation.

- **In Chapter 6**, we summarise our main results and provide a future outlook following this thesis work.

Swagat Mishra

Some aspects of the Accelerating Universe: from Inflation to Dark Energy.

An intriguing fact about our universe is that it appears to accelerate twice: once at very early times during Cosmic Inflation and then again at late times, closer to the present epoch, due to Dark Energy domination. This PhD thesis explores novel panoramas in the direction of several cosmic conundra associated with both the aforementioned periods of accelerated expansion of the universe.

Remarkable progress in our understanding of the universe over the past three decades has resulted in a firm picture of the universe in the form of the standard model of Cosmology, namely the flat ΛCDM model. This model of 'Concordance Cosmology' successfully describes the background expansion as well as the growth and formation of the large scale structure of our universe with astounding accuracy, starting from about 1 sec in the radiative hot Big Bang phase until 13.8 billion years at the present epoch.

Similarly 'Cosmic Inflation', a transient period of at least 50–60 e-folds of rapid accelerated expansion of space at early times, has emerged as the leading scenario of the very early universe, setting natural initial conditions for the standard model prior to the commencement of the radiative hot Big Bang Phase.

However in spite of these recent developments, a number of aspects of our universe remain far from being firmly established at present. This includes some aspects of the early accelerated expansion *i.e* cosmic inflation as well as some aspects of the late time acceleration during Dark Energy dominated epoch. While several distinct predictions of the single field slow-roll scenario of inflation have received spectacular observational confirmation, both from Cosmic Microwave Background (CMB) as well as Large Scale Structure(LSS) observations, the detection of the spectrum of almost scale invariant relic Gravitational waves(GWs), in the form of CMB B-mode polarization, remains one of the major challenges for the upcoming decade. Similarly a substantial period of the inflaton dynamics corresponding to potentially interesting small scale primordial physics, which accounts roughly to the last 40–50 e-folds of accelerated expansion during inflation, remains observationally unexplored, being inaccessible to the CMB and LSS observations. Another important aspect of inflationary cosmology, namely the epoch of 'reheating', remains observationally unprobed at the present, in spite of a profusion of theoretical progress in this direction. In addition, explorations of the beginning of the slow-roll phase of cosmic inflation, including initial conditions for inflation remain an interesting theoretical area of research.

Similarly at late times, the success of the standard model of Cosmology relies on the presence of the hitherto unknown dark energy to source its present accelerated expansion as well as dark matter to facilitate the formation of structure in the universe, along with explaining a multitude of Astrophysical and Cosmological phenomena. While a cosmological constant is usually preferred as the source of dark energy, fine-tuning problem associated with it combined with other conceptual challenges have lead researchers to look for dynamical models of dark energy. As per dark matter, Weakly Interacting Massive Particles (WIMPs), which are beyond the Standard Model of particle physics, are often considered as the leading candidates. However the absence of their experimental detection in spite of decades of search has directed researchers to consider possible alternatives to WIMPs, for example axions and primordial black holes (PBHs).

The present thesis explores new directions along the aforementioned cosmological quandaries.

Gitika Shukla

Probing Environment Of High Redshift Quasars using diffuse Lyman-α emission.

Quasar absorption line spectroscopy has been extensively used for the last many decades, to probe the gas in the circum-galactic medium (CGM) and inter-galactic medium (IGM) surrounding galaxies . The one-dimensional nature of absorption line studies, however, is not ideal for probing the spatial distribution of the gas surrounding individual galaxies. Therefore, in order to fully characterise the physical and kinematic properties of this gas, it is important to combine absorption and emission studies.

The diffuse nature of gas in the CGM/IGM makes direct imaging of these gas phases rather challenging. However, the UV photons from luminous sources such as quasars can ionize the neutral hydrogen (H I) gas present in the medium, with subsequent recombinations producing the Lyman-α (Lyα) 1216Å line transition which can be detected as spatially extended blobs of emitting gas (a.k.a. Lyα nebula or diffuse

Lyα emission or Lyα halo) . Detailed investigations of the spatial distribution, kinematics, and excitation of the gas traced by the extended Lyα emission can provide vital clues on various feedback processes that drive star formation and AGN activities in these high-z galaxies. The detection rate of these extended Lyα emission has gone upto 100% with the advent of integral field spectrographs (IFS) like the Multi-Unit Spectroscopic Explorer (MUSE) and the Keck Cosmic Web Imager (KCWI).

In the case of radio-loud AGN, it is possible to explore the relation between the properties of the extended Lyα emission and their radio morphology, both of which could depend on the relative orientation of the putative ionizing cone . High-z radio galaxies (HzRGs) have shown strong correlation between the radio axis and the major axis of the diffuse/optical gas emission . One of the first studies of spatially resolved Lyα emission in a large statistical sample of radio-loud quasars (RLQs) was by Heckman et al. [1991]. The halos associated with these RLQs were typically $\sim$100 kpc large with Lyα halo luminosity of $\sim$ few $\times 10^{44}$ erg s^{-1} and showed alignment between the radio axis and the Lyα morphological axes to within 30°. However, unlike in the case of HzRGs, the radio sizes of RLQs do not correlate with the sizes of the extended Lyα halos.

It is interesting to note that the samples used in the studies above are typically defined using optical colour or radio flux. The UV to optical light from the AGN can, however, be obscured by dusty material fuelling the central engine or by the dusty torus surrounding the accretion disk as proposed in AGN unification model. Reddening could also be caused by dust in the intervening medium. This could potentially inhibit the detection of these dust obscured AGN using selection techniques that rely on optical colours alone. Regardless of the origin of obscuration, it is therefore desirable to build dust-unbiased samples of AGN to distinguish between competing paradigms based on evolution or orientation to understand the AGN population itself and its impact on galaxy evolution via feedback. Among various selection techniques – such as those based on optical colors, X-ray luminosity and radio flux – the mid-infrared (MIR) color selection based on the AllWISE catalog from the Wide-field Infrared Survey Explorer (WISE) in its four bands, namely W1 (3.4 μm), W2 (4.6 μm), W3 (12 μm), and W4 (22 μm), is widely used to construct dust-unbiased samples of AGN.

In this thesis, we will study the properties of radio-loud AGN along with their influence on their environments. In order to ensure that our study is dust-unbiased, we have used WISE MIR-colors (i.e $W_1 - W_2 < 1.3 \times (W_2 - W_3) - 3.0$ and $W_1 - W_2 > 0.6$) [see Fig 1 of Krogager et al. 2018] to construct a sample of AGN candidates for follow up spectroscopic survey using Nordic Optical Telescope (NOT) and the Southern African Large Telescope (SALT) to confirm the redshift and nature of these sources. The WISE color cut chosen is used to efficiently select quasars at $z > 1.4$. This sample (which we refer to as SALT-NOT) is based on the following three criteria: *(i)* flux density > 200 mJy at $\sim$1 GHz, *(ii)* $\delta < +20°$, and *(iii)* MIR-colors consistent with equation given above. The SALT-NOT sample definition is based on the requirements of MeerKAT Absorption Line Survey [MALS; see Gupta et al. 2016, for key science objectives], an ongoing large survey at the South African precursor of the upcoming Square Kilometer Array (SKA) and these objects from SALT-NOT will be the main targets for MALS.

We have a total of 303 new AGN, all being extremely radio-loud (median $R = 3685$) and brighter than 200 mJy at 1.4 GHz, with 250 being in the redshift range $0 < z < 5$. This sample of SALT-NOT AGN forms an excellent resource for a broad range of science goals. In this thesis, we will first measure the redshifts of the objects in this sample and characterise the sample using various properties such as black hole mass, continuum luminosity, etc. We will then use a subset of this sample at $z > 2.7$ to study the spatial distribution of gas using Lyα emission. We also search for damped Lyα systems (DLAs) and associated Lyα emission in this sample. This is the first statistical study of spatially extended Lyα emission in a dust-unbiased, large sample of extremely bright radio-loud AGN.

R. Sujatha

Halo Dynamics and Kinematics: Applications to Large-Scale Structure and Cosmology

The physical connection between the growth and properties of gravitationally collapsed haloes of dark matter haloes and the cosmic web environment in which these haloes reside is an interesting and challenging problem in the study of hierarchical structure formation [White and Silk, 1979, Eisenstein and Loeb, 1995, Bond and Myers, 1996, Bond et al., 1996, Monaco, 1999, Sheth and Tormen, 1999]. The large-scale clustering or the density environment of the dark matter haloes is a key variable in understanding the formation and evolution of the large-scale structure of the Universe [see Desjacques et al., 2018 for a review]. Although the basic statistical connection between the very large-scale density environment (or halo bias) and halo properties such as mass was already established several decades ago [Kaiser, 1984, Bardeen et al., 1986, Bond et al., 1991, Lacey and Cole, 1993, Mo and White, 1996], an enhanced understanding of the dark matter halo and consequently, galaxy formation and evolution thus requires us to explore deep correlations - *which is also the focus of this thesis* - between the large-scale halo bias and internal properties of the halos such as formation time, concentration, substructure abundance, shape, velocity dispersion structure, angular momentum, local tidal morphologies etc. This was also necessitated by the subsequent technological improvements in simulating cold, collisionless self-gravitating cosmological systems which have revealed several of these additional features of dark matter haloes [see, e.g., Sheth and Tormen, 2004, Gao et al., 2005, Wechsler et al., 2006, Jing et al., 2007, Faltenbacher and White, 2010, Shen et al., 2006].

The term halo assembly bias is used to describe the correlation between internal properties of dark matter haloes and the large-scale halo clustering strength at fixed halo mass which are also strongly affected by the local, non-linear cosmic web. Apart from the intrinsic interest in painting a more complete picture of hierarchical structure formation from first principles, understanding and calibrating these effects also continues to be of interest from the point of view of galaxy formation and evolution [see, e.g., Yan et al., 2013, Tinker et al., 2017, Paranjape et al., 2018a, Alam et al., 2019, Wang et al., 2018, Zehavi et al., 2018]. It is also a potential source of systematic uncertainty for cosmological inference from upcoming large-volume galaxy surveys [Zentner et al., 2014, McEwen and Weinberg, 2018].

In this **thesis**, we examine the effect of the halo's local environment on its assembly bias by characterising a halo's local web environment by its tidal anisotropy α at scales $\sim 4\times$ the halo radius. We focus on scalar internal properties of haloes related to formation time (concentration $c_{\rm vir}/c_{200b}$), shape (mass ellipsoid asphericity c/a), velocity dispersion structure (velocity ellipsoid asphericity c_v/a_v and velocity anisotropy β) and angular momentum (dimensionless spin λ). In **chapter 2**, we introduce all of the above properties.

In **chapter 3** of the thesis which is based on [Ramakrishnan et al., 2019, 2021], we demonstrate that these multi-scale correlations represent *two distinct statistical links*: one between the internal property and α, and the other between α and large-scale ($\gtrsim 30h^{-1}$Mpc) halo bias b_1. The halo-by-halo bias allows us to treat clustering as another property of individual haloes and perceive the assembly bias as a correlation between two variables, namely halo-by-halo bias b_1 and halo property c. Using conditional correlation coefficients and other detailed tests, we show that the joint distribution of α, b_1 and *any* of the internal properties $c \in \{\beta, c_v/a_v, c/a, c_{\rm vir}, \lambda\}$ is consistent with $p(\alpha, b_1, c) \simeq p(\alpha)p(b_1|\alpha)p(c|\alpha)$, at all but the largest masses. *Thus, the assembly bias trends $c \leftrightarrow b_1$ reflect the two fundamental correlations $c \leftrightarrow \alpha$ and $b_1 \leftrightarrow \alpha$.* In other words, there is no residual assembly bias once the tidal anisotropy is fixed. Our results are unaffected by the exclusion of haloes with recent major merger events or splashback objects, although the latter are distinguished by the fact that α *does not* explain their assembly bias trends.

Figure 1 shows the main results of this chapter. The left panel shows Spearman rank correlation coefficients (for haloes in fixed bins of virial mass $M_{\rm vir}$) between the tidal anisotropy α and other halo properties including halo bias b_1 and all the five internal properties c. This panel summarizes a number of previously known results, including the observations that, at fixed mass, haloes in more anisotropic tidal environments tend to be more strongly clustered [$\alpha \leftrightarrow b_1$, Hahn et al., 2009, Paranjape et al., 2018b], more concentrated [$\alpha \leftrightarrow c_{\rm vir}$, Paranjape et al., 2018b], more spherical [$\alpha \leftrightarrow c/a$, Wang et al., 2011], with higher spin [$\alpha \leftrightarrow \lambda$, Hahn et al., 2009, Wang et al., 2011], and have more tangentially dominated velocity distributions [$\alpha \leftrightarrow \beta$, Borzyszkowski et al., 2017]. Additionally, we see that objects in anisotropic environments also have more spherical velocity ellipsoids ($\alpha \leftrightarrow c_v/a_v$), with a correlation very similar at all masses to that between α and the mass ellipsoid asphericity c/a.

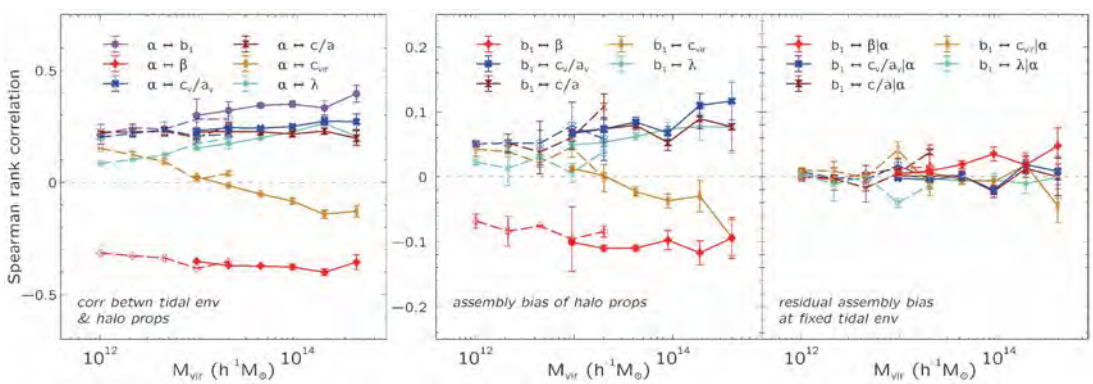


Figure 1: **Correlations between internal halo properties, tidal environment and large-scale bias.** *(Left panel:)* Spearman rank correlation coefficients, for haloes in bins of mass $M_{\rm vir}$, between tidal anisotropy α and other halo properties, including $\gamma_{\alpha b_1}$ with large-scale bias b_1 and $\gamma_{\alpha c}$ with internal properties $c \in \{\beta, c_v/a_v, c/a, c_{\rm vir}, \lambda\}$ (see caption of Figure 1 of Ramakrishnan et al. [2019]). In the legend, each coefficient γ_{ab} is represented by the symbol $a \leftrightarrow b$. *(Middle panel:)* Assembly bias trends seen using Spearman rank correlation coefficients $\gamma_{b_1 c}$ between halo bias and each internal property c (c.f. Figure 1 of Ramakrishnan et al. [2019]). *(Right panel:)* Conditional correlation coefficients $\gamma_{b_1 c|\alpha}$ (equation 12 of Ramakrishnan et al. [2019]) for each internal property c. Note that the vertical axis in the middle and right panels is zoomed in by a factor ~ 3 as compared to the left panel. In each panel, filled symbols joined with solid lines show the mean over 10 realisations of the $300h^{-1}$Mpc box, with error bars showing the scatter around the mean, while open symbols joined with dashed lines show measurements using 2 realisations of the $150h^{-1}$Mpc box. *The right panel shows the main result of this work:* each conditional coefficient $\gamma_{b_1 c|\alpha}$ is substantially smaller in magnitude than the corresponding unconditional coefficient $\gamma_{b_1 c}$ in the middle panel. Thus, conditioning on tidal anisotropy α largely accounts for the assembly bias trend of *all* internal halo properties. See text for a discussion.

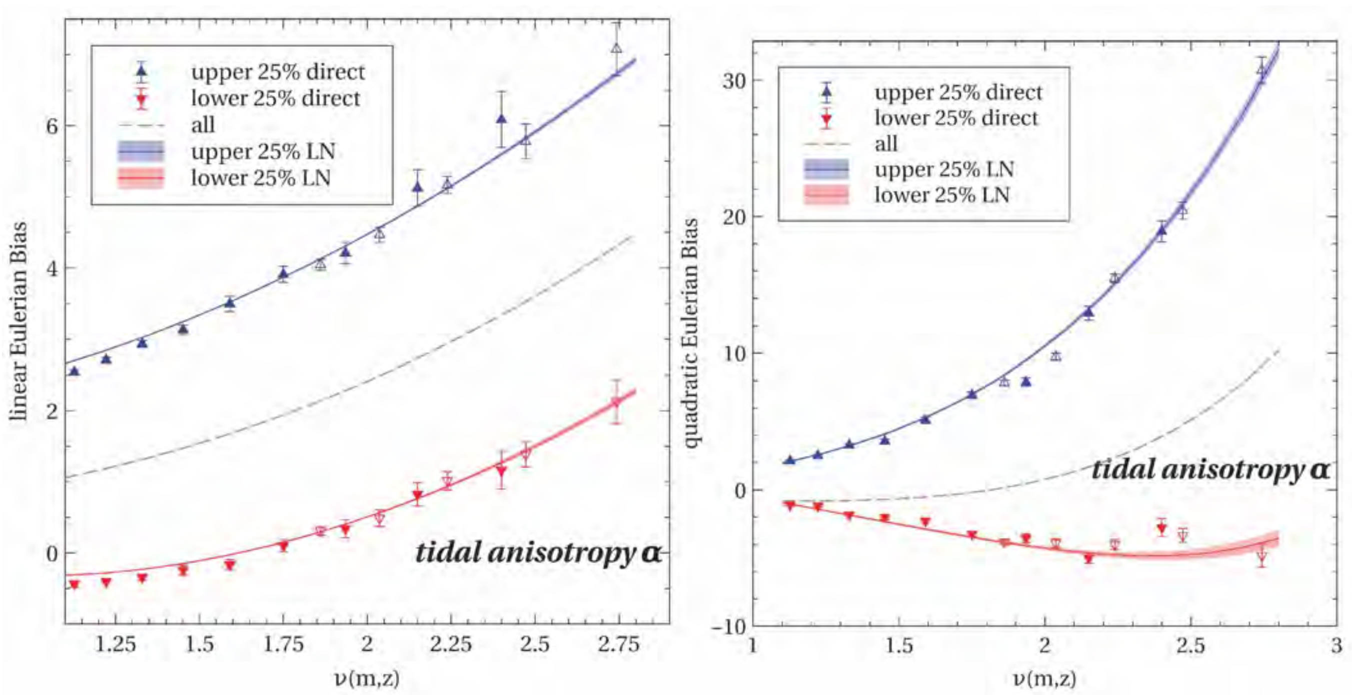


Figure 2: Linear halo bias b_1 as a function of peak height ν for upper and lower quartiles of α (i.e., $\tilde{\alpha} < -0.675$ and $\tilde{\alpha} > 0.675$). The data points with error bars are obtained from simulations (see section 2.2 of Ramakrishnan and Paranjape [2020]). The two solid curves in both panels are obtained by taking the Lognormal model $b_1^L(m, \tilde{\alpha})$ and $b_2^L(m, \tilde{\alpha})$ averaging within the upper and lower quartile of $\tilde{\alpha}$. The covariance matrix from Table 2 of Ramakrishnan and Paranjape [2020] is used to sample μ_1^L, Σ_1^L, μ_2^L and Σ_2^L 300 times and the standard deviation of $b_1^L(m, \tilde{\alpha})$ and $b_2^L(m, \tilde{\alpha})$ computed from each of these times is plotted as an error band around the solid curves. The black dashed curve shows the analytic fit for the linear bias of all haloes from Tinker et al. [2010] and Lazeyras et al. [2016].

The middle panel of Figure 1 summarizes the known assembly bias trends. Note that we have zoomed in on the vertical axis as compared to the left panel; the correlations of halo properties with large-scale bias are weaker (by approximately a factor ~ 3 in each case) than the respective correlations with the local tidal environment.

The right panel of Figure 1 shows our main new result: we display the conditional correlation coefficients $\gamma_{b_1 c|\alpha}$ (calculated using equation 12 of Ramakrishnan et al. [2019]) for each internal property c. The vertical scale is identical to that in the middle panel which showed the corresponding unconditional coefficients using the same scheme for colours and markers. In each case, we see that the conditional coefficients are substantially smaller in magnitude than the corresponding unconditional ones at all masses (by a factor ~ 4 or so at low masses). In fact, except for β around $\sim 10^{14} h^{-1} M_\odot$ (see below), the conditional coefficients are scattered around zero in all cases over the entire mass range, implying that α is an excellent candidate for the primary environmental variable responsible for halo assembly bias trends.

Another clustering statistic that captures small scale halo clustering in addition to the large scale clustering is the two-point correlation function. We demonstrate that the two-point correlation function of a halo sub-population of a fixed mass range (selected by a particular halo property) remains invariant under a random shuffling of halos within bins of tidal anisotropy α. The overarching importance of α provides a new perspective on the nature of assembly bias of distinct haloes, with potential ramifications for incorporating realistic assembly bias effects into mock catalogs of future large-scale structure surveys and for detecting galaxy assembly bias.

In **chapter 4** which is based on [Ramakrishnan and Paranjape, 2020, Ramakrishnan et al., 2021], our primary aim was to use the Separate Universe technique to calibrate the dependence of linear and quadratic halo bias b_1 and b_2 on the local cosmic web environment of dark matter haloes. We do this by measuring the response of halo abundances at fixed mass and cosmic web tidal anisotropy α to an infinite wavelength initial perturbation. We augment our measurements with an analytical framework developed in earlier work [Paranjape and Padmanabhan, 2017] which exploits the near-Lognormal shape of the distribution of α and results in very high precision calibrations.

We present convenient fitting functions for the dependence of b_1 and b_2 on α over a wide range of halo mass for redshifts $0 \leq z \leq 1$.

Our calibration of $b_2(\alpha)$ is the first demonstration to date of the dependence of non-linear bias on the local web environment. Motivated by results in the previous chapter which showed that α is the primary indicator of halo assembly bias for a number of halo properties beyond halo mass, we then extend our analytical framework to accommodate the dependence of b_1 and b_2 on any such secondary property which has, or can be monotonically transformed to have, a Gaussian distribution. We demonstrate this technique for the specific case of halo concentration (and for all other four properties later in the next chapter), finding good agreement with previous results. We reproduce the known dependence of $b_1(c_{200b}, \nu)$ accurately over our entire dynamic range, while $b_2(c_{200b}, \nu)$ departs from previous results at low peak height ν. Our calibrations will be useful for a variety of halo model analyses focusing on galaxy assembly bias, as well as analytical forecasts of the potential for using α as a segregating variable in multi-tracer analyses. Figures 2 summarise the main result of this chapter. The solid curves in left panel of Figure 2 show the analytic framework for b_1 applied to the halo populations in upper and lower quartiles of α; these are obtained using equation 12 of Ramakrishnan and Paranjape [2020] averaged over the quartiles of the standardised tidal anisotropy weighted by the standard Gaussian distribution.

For comparison, we also compute the peak-background split bias for these two halo populations separately. The results, shown as the two sets of points with error bars in Figure 2, agree well with the analytical framework, but with larger errors. Thus, our framework is a very convenient noise reduction technique for computing halo assembly bias, as noted previously by Paranjape and Padmanabhan [2017].

The right panel of Figure 2 shows the difference in b_2 for the upper and lower quartiles of the tidal anisotropy α. Interestingly, the upper and lower quartiles have opposite signs in all the mass ranges. The upper quartile population having positive values is expected from the extreme non-Gaussianities and non-linearities present in the spatial distribution of haloes in dense filamentary (high α) environment. The near-zero, slightly negative b_2 of haloes in isotropic regions (low α quartile) is more complicated, as it could either have negative skew from being in an underdense void or a positive skew from being in an overdense cluster. We can see that the dependence on the environment is clearly strong; the relative difference between any quartile b_1 and mean b_1 is of the order of unity while the relative difference between any quartile and mean b_2 is of the order of 10.

Unlike b_1, the α-dependence of b_2 is also a strong function of ν, consistent with the expectation that b_2 depends on significantly more nonlinear scales than does b_1. Similar to b_1, our formalism allows for the computation of b_2 at fixed α, not just in bins of α.

In **Chapter 5** of the thesis which is based on [Ramakrishnan et al., 2021], we discuss an application of the above ideas which is useful to create large volume mock halo catalog. Large-scale sky surveys require companion large volume simulated mock catalogs. To ensure precision cosmology studies are unbiased, the correlations in these mocks between galaxy properties and their large-scale environments must be realistic. Since galaxies are embedded in dark matter haloes, an important first step is to include the effect of assembly bias for dark matter haloes. However, galaxy properties correlate with smaller scale physics in haloes which large simulations struggle to resolve. We describe an algorithm which addresses and largely mitigates this problem. Our algorithm exploits the fact that halo assembly bias is unchanged as long as correlations between halo property c and the intermediate-scale tidal environment α are preserved. Therefore, knowledge of α is sufficient to assign small-scale, otherwise unresolved properties to a halo in a way which preserves its large-scale assembly bias accurately. We demonstrate this explicitly for halo internal properties like formation history (concentration c_{200b}), shape c/a, dynamics c_v/a_v, velocity anisotropy β and angular momentum (spin λ). Our algorithm increases a simulation's reach in halo mass

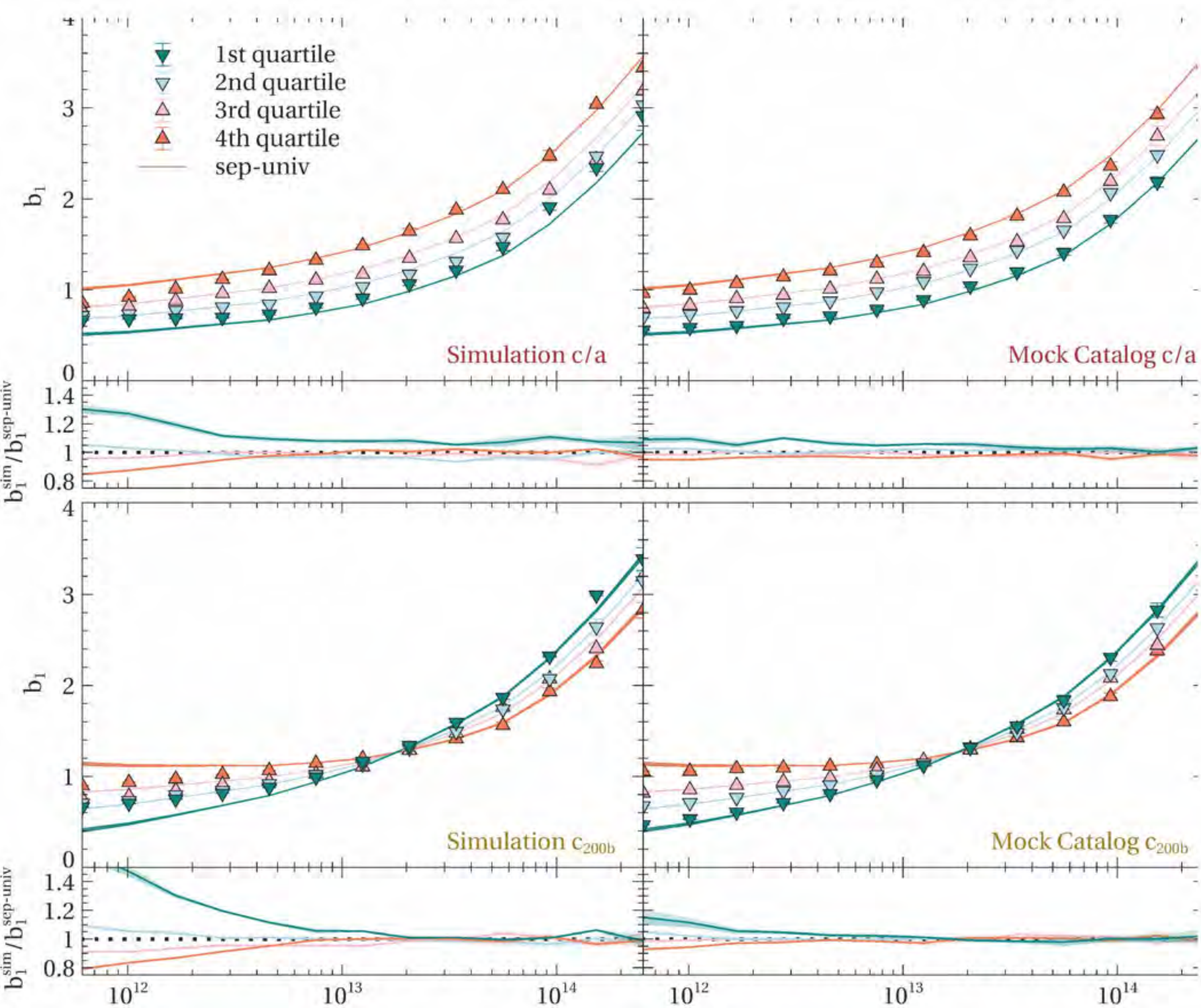


Figure 3: Comparison of assembly bias due to halo shape c/a (top row) and concentration c_{200b} (bottom row) in our large-volume, low-resolution simulations and corresponding mocks with Separate Universe (SU) calibrations. For each halo property c, the four different coloured data markers show the average halo bias in the four quartiles of c, with values c measured directly in the low-resolution simulation (left panels) and assigned by our conditional sampling algorithm (right panels). The solid curves, repeated for each property in the corresponding left and right panel, show the calibration for assembly bias using the SU technique from equation 27 of [Ramakrishnan and Paranjape, 2020]. The small lower sub-panels in each case show the ratio of each assembly bias curve with the SU calibration. Low-mass haloes resolved with $\lesssim 300$ particles (halo masses $\lesssim 4.6 \times 10^{12} h^{-1} M_\odot$) in the simulation (left hand panels) fail to reproduce the full strength of assembly bias, while corresponding haloes in the mock catalogs (right hand panels) perform much better down to a 30 particle threshold.

and number density by an order of magnitude, with improvements in the bias signal as large as 45% for 30-particle haloes, thus significantly reducing the cost of mocks for future weak lensing and redshift space distortion studies. Figures 3 summarises the main results of this chapter and they compare the corresponding assembly bias with that measured in the original (resolution compromised) simulation for a range of choices for c. As reference values, we use the calibrations of large-scale, scale-independent assembly bias from the Separate Universe (SU) technique presented in the previous chapter which take as input the correlation between Gaussianized c and standardised tidal anisotropy $\tilde{\alpha}$. Besides being a different approach to measuring halo bias, the SU calibrations are both very accurate and not limited by box-size effects. The panels on the left show that, typically, the results in the original low-resolution simulation show a smaller assembly bias signal than the SU reference. In contrast, our mock sampling technique does not suffer from this drawback, since it is built using fitting functions that used well-resolved haloes in high-resolution simulations to access low halo masses. The panels on the right show that our mocks are clearly closer to the reference (SU) than are the original simulations, especially at low masses. The mocks typically agree with the SU calibration to better than $\sim 5\%$ ($\sim 15\%$) for the middle (outer) quartiles of *all* halo properties down to the 30 particle limit of the simulation. Additionally, for haloes resolved with $\lesssim 300$ particles, the mocks substantially outperform the raw (resolution compromised) measurements. Figures 3 demonstrates the power and accuracy of our mock making approach.

The thesis in summary, gives us reasons to approach or view the residual beyond mass dependence of halo clustering on cosmic web environment as the primary driver of all the other correlations with internal properties and discusses implications and applications of such an approach.

List of Publications

1. *Mock halo catalogues: assigning unresolved halo properties using correlations with local halo environment*, https://ui.adsabs.harvard.edu/abs/2021MNRAS.503.2053R,

   S. Ramakrishnan, A. Paranjape, R. K. Sheth, **MNRAS, 503, 2053**,arXiv:2012.10170.
2. *Separate Universe calibration of the dependence of halo bias on cosmic web anisotropy*, https://ui.adsabs.harvard.edu/abs/2020MNRAS.499.4418R,

   S. Ramakrishnan, A. Paranjape,**MNRAS, 499, 4418**, arXiv:2007.03711.
3. *Cosmic web anisotropy is the primary indicator of halo assembly bias*, https://ui.adsabs.harvard.edu/abs/2019MNRAS.489.2977R, **S. Ramakrishnan**, A. Paranjape, O. Hahn, and R. K. Sheth, **MNRAS, 489, 2977**, arXiv:1903.02007.

FACILITIES AT IUCAA

Computing Facility

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

The hardware and devices currently managed by the computing facility include about 340+ servers and desktops, 100+ laptops, 45+ printers and scanners, three large High Performance Computing Clusters and over 8 Pebibyte (PiB) of storage, in addition to diverse equipment deployed for an extensive, high throughput wired and wireless campus-wide network. The number of registered WiFi devices is over 900 and e-mail accounts served by the computing facility amount to nearly 700.

IUCAA provides e-mail services to its members and associates, the total number of accounts being nearly 700. IUCAA has its own registered domain name as "iucaa.in". The WAN services are provided by the National Knowledge Network on a 1 Gbps fibre connectivity, with a fall back arrangement on a 50 Mbps line from TATA VSNL.

In the year April 2021- March 2022 emphasis was given to implementation of:

1) Archival storage for MALS:

The Meerkat Absorption Line Survey (MALS), led by IUCAA scientists, is one of the ten extensive surveys being carried out with the MeerKAT telescope in South Africa. The data will be transferred from South Africa to IUCAA through tapes (LTO7 or better) and will be processed IUCAA by MALS team. The data for MALS is segregated on three storages, hot (fast), warm (intermediate) and cold (slow). The warm storage acts as an archival storage. We have procured and installed 1PiB archival storage for MALS.

2) Wired LAN connectivity in Housing colony

During the lockdown period, most of the students, staff and faculty in the housing colony have been working from home. In order to facilitate this, we have enhanced the coverage of wired LAN connectivity in the housing colony. In this project, we provided LAN connectivity to Type-II and Type-III quarters.

3) Procurement of 500 compute cores for High Performance Computing Cluster (Pegasus):

The Pegasus cluster deployed in 2019 consist of two login nodes, two graphics nodes, 1920 compute cores, 2PiB PFS storage. In the last two years, several new users have been added and all users are extensively using the cluster. Currently, the average cluster utilisation is more than 90%, resulting in a considerable wait time for many jobs. After looking at the usage trend, the computer users committee approved expansion of the Pegasus cluster by adding 500 compute cores. The procurement of the compute cores is in process.

4) Support for Online INAT exam

Due to the pandemic situation, the INAT exam was conducted online through M/s CondeTantra. CodeTrantra uses third-eye technology to monitor all candidates and records the activity of candidates. We have provided support in the procurement of the online examination software and provided required software environment to transfer essential data from CodeTanra to IUCAA.

5) Provisioning Wired and Wi-FI Network infrastructure

Considering pandemic situation stable wired and Wi-fi connectivity was must and on priority provisioning of fibre connectivity along with Network infrastructure is successfully carried out for Type II ,Type III quarters, TLC Building, PKC office in SPPU Campus.

6) Upgradation of existing firewall:

IUCAA currently have SonicWall NSA 4600 UTM firewall configured in High Availability with perpetual VPN license for both IUCAA and LIGO networks. It is *responsible for security of entire campus network*. Considering growing network requirements and security threats, upgradation of existing firewall with a latest generation firewall with a buy back option of existing one is explored, procured and installed successfully.

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

HP lasejet Colour M775 printer (Qty. 1), HP All in one Desktop (Qty 30), HP Laptop (Qty. 12), and MacBook Pro (Qty. 5) were acquired for the academic community, visitors and administrative officers.

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

The Computing Facility employs 8 personnel, who carry out the daily functions that include:

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

2. Framing policy documents and finalizing them in consultation with the Computer Users' committee members.

3. Drawing up specification of the RFP (Request For Proposal) tender document for IUCAA IT required to be purchased and oversee all purchases related procedure and follow up.

4. Maintenance of IT hardware in the campus including servers, desktops, mobile computing equipment, printers etc.

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

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

7. Configuration and management of data backups.

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

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

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

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

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

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

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

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

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

17. Hardware Maintenance and General System Administration of clusters in IUCAA in coordination with OEM.

18. Assisting Estate Department with Data Center management activities.

19. Architecting new hardware solutions to address operational needs.

High Performance Computing

IUCAA currently has three major independent HPC clusters dedicated to different applications, namely Pegasus, SARATHI and VROOM.

The **Pegasus Cluster** is to serve the general computing requirement of the astronomy community associated with IUCAA. It has 60 compute nodes, each with 32 cores and 384 GB RAM. It uses InfiniBand EDR (100Gbps) as an inter-connect, and Portable Batch System (PBS) as a job scheduler. For visualisation purposes, there are two dedicated graphics nodes equipped with NVIDIA Tesla P100 GPU cards. The cluster is attached to a 2 PiB parallel file system (Lustre), which is capable of delivering 15 GBps throughput. Theoretical computing speed of the Pegasus Cluster is 100 TF. The Pegasus cluster has been utilized by about 70 high volume users from IUCAA and various Indian Universities, running applications for Molecular Scattering, Molecular Dynamics, Stellar Dynamics, Gravitational N-Body Simulations, Cosmic Microwave Background Evolution, Fluid Mechanics, Magnetohydrodynamics, Plasma Physics, and the analysis of diverse astronomical data.

The **Sarathi Cluster** is primarily used for gravitational wave research and is mostly used by national and international members of the LIGO Scientific Collaboration, Virgo and KAGRA (LVK) / International Gravitational-Wave Observatory Network (IGWN), which includes many IUCAA members and Associates. The cluster is comprised of heterogeneous compute servers, it is built in three phases. The cluster consists of more than 8000 Physical cores. The theoretical peak performance of the compute node CPUs of the cluster is nearly 530 TFlops. The cluster has 2PiB PFS storage with 30Gbps write and read (1:1) throughput.

The **Vroom cluster** is used solely for the MeerKAT Absorption Line Survey (MALS). This cluster has 16 compute nodes (DELL) which delivers 25 TF computing speed and has a parallel file system (DDN) of 3.5 PiB usable capacity attached to it.

HPC clusters listed in Top Supercomputers in India

Sarathi Cluster Phase III, Pegasus Cluster, and Sarathi Cluster Phase II are listed at 25th, 37th and 40th rank respectively in the list of top Supercomputers in India published on January 31, 2022. The list is maintained and supported by CDAC's Terascale Supercomputing Facility (CTSF), CDAC, Bangalore. The list is available at http://topsc.cdacb.in/topsc.php/filterdetails?slug=January2022

IUCAA High Performance Computing clusters, Perseus, Pegasus and Sarathi.

[Picture Credit: Mr. Shashank Tarape]

Chiller plant assembly for IUCAA Datacentre.

[Picture Credit: Mr. Shashank Tarape]

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

(Picture Credit: Mr. Shashank Tarape)

The IUCAA Library

The IUCAA library provides access to a comprehensive collection of books and journals in astronomy, astrophysics, and related areas. In addition to the Springer Physics and Astronomy eBook collection for 2021-22, comprising 390 titles, the library purchased 177 publisher-specific eBooks, as below.

Publisher	Number of eBooks
Annual Reviews	02
De Gruyter	93
Institute of Physics	37
John Wiley and Sons	45

The library also renewed its subscription to Grammarly Premium and the Overleaf premium software. Further, the library renewed its subscription to 78 journals.

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

The library deployed a middleware solution, 'RemotLog,' to facilitate off-campus access to the library subscribed e-resources. The e-resources from the following publishers have been accessed by users, including Visiting Associates of IUCAA.

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

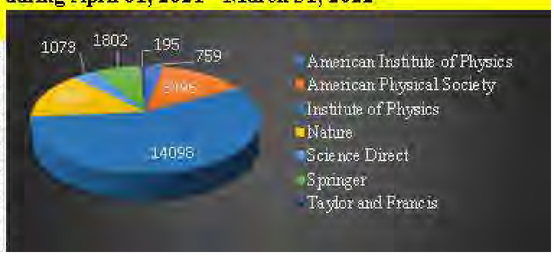
The E-Books and E-Journals usage during the year is depicted below:

E-Books usage during April 01, 2021 - March 31, 2022

Publisher	Count
Cambridge University Press	10118
Institute of Physics	148
Oxford University Press	694
Springer Nature	6359
World Scientific Press	66

E-Journals usage during April 01, 2021 - March 31, 2022

Publisher	Count
American Institute of Physics	759
American Physical Society	3496
Institute of Physics	14098
Nature	3582
Science Direct	1073
Springer	1802
Taylor and Francis	195



The library team of five professionals facilitated the following activities and services:

1. Document Delivery Service for articles and book chapters — fulfilled 273 article requests from 144 users and 07 book chapter requests from 04 users.

2. The library processed 15 publication charge requests.

3. The library assisted four users in ordering 15 books from their contingency grant.

4. The library provided plagiarism reports using Ouriginal for research papers and Ph.D. thesis.

5. The IUCAA library YouTube channel presently has 207 videos with a subscriber base of 6567 and 89581 views.

6. The library staff assisted the Publications Section in the compilation of the following content for the Annual Report:
   a) Publications by IUCAA Academics.
   b) Publications by Visiting Associates (along with Visitor Services).
   c) Pedagogical.
   d) IUCAA Centres for Astronomy Research and Development (ICARDs).

RESEARCH BY VISITING ASSOCIATES

Gouri Ambika

Frequency chimera state induced by differing dynamical timescales

We report the occurrence of a self-emerging frequency chimera state in spatially extended systems of coupled oscillators, where the coherence and incoherence are defined with respect to the emergent frequency of the oscillations. This is generated by the local coupling among nonlinear oscillators evolving under differing dynamical timescales starting from random initial conditions. We show how they self-organize to structured patterns with spatial domains of coherence that are in frequency synchronization, coexisting with domains that are incoherent in frequencies. Our study has relevance in understanding such patterns observed in real-world systems like neuronal systems, power grids, social and ecological networks, where differing dynamical timescales is natural and realistic among the interacting systems. This work has been done in Collabration with Sneha Kachhara.

Emergent Dynamics and Spatio temporal Patterns on Multiplex Neuronal Networks

We present a study on the emergence of a variety of spatio temporal patterns among neurons that are connected in a multiplex framework, with neurons on two layers with different functional couplings. With the Hindmarsh-Rose model for the dynamics of single neurons, we analyze the possible patterns of dynamics in each layer separately and report emergent patterns of activity like in-phase synchronized oscillations and amplitude death (AD) for excitatory coupling and anti-phase mixed-mode oscillations (MMO) in multi-clusters with phase regularities when the connections are inhibitory. When they are multiplexed, with neurons of one layer coupled with excitatory synaptic coupling and neurons of the other layer coupled with inhibitory synaptic coupling, we observe the transfer or selection of interesting patterns of collective behavior between the layers. While the revival of oscillations occurs in the layer with excitatory coupling, the transition from anti-phase to in-phase and vice versa is observed in the other layer with inhibitory synaptic coupling. We also discuss how the selection of these spatio temporal patterns can be controlled by tuning the intralayer or interlayer coupling strengths or increasing the range of non-local coupling. With one layer having electrical coupling while the other synaptic coupling of excitatory(inhibitory)type, we find in-phase(anti-phase) synchronized patterns of activity among neurons in both layers. This work has been done in collaboration with Umesh Kumar Verma.

Sampurn Anand

Generating Seed magnetic field **à** *la The Chiral Biermann battery*

Cosmological and astrophysical observations indicate the presence of magnetic field over all scales. In order to explain these magnetic fields, it is assumed that there exists a seed magnetic field that gets amplified by dynamos. These seed fields may have been produced during inflation, at phase transitions, or some turbulent phase of the early universe. One well-known mechanism to get the seed field is the Biermann battery, which was originally discussed in the context of generation in an astrophysical object. Requirements for this mechanism to work are (i) non-zero gradient of the electron number density and pressure, (ii) they are non-parallel to each other. In the present article, we propose a similar mechanism to generate the seed field but in inhomogeneous chiral plasma. Our mechanism works, in presence of chiral anomaly, by the virtue of inhomogeneity in the chiral chemical potential and temperature. We will discuss various scenarios where inhomogeneities in the chemical potential and temperature can arise. We found that, depending on the epoch of generation, the strength of the seed magnetic fields varies from a few nano-Gauss (nG) to a few hundred nG. This work has been done in collaboration with Arun Pandey.

Tanwi Bandyopadhyay

Accretions of Tsallis, Renyi and Sharma-Mittal dark energies onto (n+2)-dimensional Schwarzschild black hole and Morris-Thorne wormhole

We study the dark energy accretion phenomena onto $(n+2)$-dimensional Schwarzschild black hole and $(n+2)$-dimensional Morris-Thorne wormhole. We obtain the $(n+2)$-dimensional Schwarzschild black hole mass and $(n+2)$-dimensional Morris-Thorne wormhole mass and their rate of change of masses due to accretion. For the dark energy component, we consider Tsallis, modified Rényi and 'modified' Sharma-Mittal holographic dark energy (HDE) and new agegraphic dark energy (NADE). We also find the black hole mass and the wormhole mass in terms of redshift when cold dark matter and the specified forms of dark energies accrete onto them. In most the cases, the black hole mass increases, and wormhole mass decreases for HDE and NADE accretions. The only exception is the Sharma-Mittal NADE, where the black hole mass decreases and wormhole mass increases during the evolution of the Universe. However, the slope of increasing/decreasing mass significantly depends on the dimension in almost all cases.This work has been done in collaboration with Ujjal Debnath.

Arunima Banerjee

HI 21 cm observation and mass models of the extremely thin galaxy FGC 1440

We present observations and models of the kinematics and distribution of neutral hydrogen (HI) in the superthin galaxy FGC 1440 with an optical axial ratio $a/b = 20.4$. Using the Giant Meterwave Radio telescope (GMRT), we imaged the galaxy with a spectral resolution of 1.7 kms^{-1} and a spatial resolution of 15.9" 13.5". We find that FGC 1440 has an asymptotic rotational velocity of 141.8 kms^{-1}. The structure of the H I disc in FGC 1440 is that of a typical thin disc warped along the line of sight, but we cannot rule out the presence of a central thick HI disc. We find that the dark matter halo in FGC 1440 could be modelled by a pseudo-isothermal (PIS) profile with $R_c/R_d < 2$, where R_c is the core radius of the PIS halo and Rd the exponential stellar disc scale length. We note that in spite of the unusually large axial ratio of FGC 1440, the ratio of the rotational velocity to stellar vertical velocity dispersion, $V_{\rm rot}/\sigma_{\rm z} \sim 58$, which is comparable to other superthins. Interestingly, unlike previously studied superthin galaxies which are outliers in the $\log 10(j*) - \log 10(M*)$ relation for ordinary bulgeless disc galaxies, FGC 1440 is found to comply with the same. The values of j for the stars, gas, and the baryons in FGC 1440 are consistent with those of normal spiral galaxies with similar mass. This work has been done in collaboration with K. Aditya, Peter Kamphuis, Sviatoslav Borisov, Aleksandr Mosenkov, Aleksandra Antipova, and Dmitry Makarov.

Indrani Banerjee

Looking for extra dimensions in the observed quasi-periodic oscillations of black holes

Quasi-periodic oscillations, often present in the power density spectrum of accretion disk around black holes, are useful probes for the understanding of gravitational interaction in the near-horizon regime of black holes. Since the presence of an extra spatial dimension modifies the near horizon geometry of black holes, it is expected that the study of these quasi-periodic oscillations may shed some light on the possible existence of these extra dimensions. Intriguingly, most of the extra dimensional models, which are of significant interest to the scientific community, predicts the existence of a tidal charge parameter in black hole spacetimes. This tidal charge parameter can have an overall negative sign and is a distinctive signature of the extra dimensions. Motivated by this, we have studied the quasi-periodic oscillations for a rotating braneworld black hole using the available theoretical models. Subsequently, we have used the observations of the quasi-periodic oscillations from available black hole sources, e.g., GRO J1655-40, XTE J1550-564, GRS 1915 + 105, H 1743 + 322 and Sgr A* and have compared them with the predictions from the relevant theoretical models, in order to estimate the tidal charge parameter. It turns out that among the 11 theoretical models considered here, 8 of them predict a negative value for the tidal charge parameter, while for the others negative values of the tidal charge parameter are also well within the 1-σ confidence interval. This work has been done in collaboration with Sumanta Chakraborty and Soumitra SenGupta.

Critical analysis of modulus stabilization in a higher dimensional F(R) gravity

An exact solution for the bulk five-dimensional geometry is derived for F(R) gravity with nonflat de Sitter 3-branes located at the $M_4 \times Z_2$ orbifold boundaries. The corresponding form of F(R) that leads to such an exact solution of the bulk metric is derived, which turns out to have all positive integer powers of R. In such a scenario, the stability issue of the modulus (radion field) is analyzed critically for different curvature epochs in both Einstein and Jordan frames. The radion in the effective 4D theory exhibits a phantom epoch, making this model viable for a nonsingular bounce. Simultaneous resolution of the gauge-hierarchy problem is exhibited through the resulting stable value of the radion field in the effective 3+1-dimensional theory.

This work has been done in collaboration with Tanmoy Paul and Soumitra SenGupta.

Aru Beri

The evolving radio jet from the neutron star X-ray binary 4U 1820–30

The persistently bright ultra-compact neutron star low-mass X-ray binary 4U 1820–30 displays a ∼170 d accretion cycle, evolving between phases of high and low X-ray modes, where the 3–10 keV X-ray flux changes by a factor of up to 8. The source is generally in a soft X-ray spectral state, but may transition to a harder state in the low X-ray mode. Here, we present new and archival radio observations of 4U 1820–30 during its high and low X-ray modes. For radio observations taken within a low mode, we observed a flat radio spectrum consistent with 4U 1820–30 launching a compact radio jet. However, during the high X-ray modes the compact jet was quenched and the radio spectrum was steep, consistent with optically-thin synchrotron emission. The jet emission appeared to transition at an X-ray luminosity of L_X(3–10 keV)$\sim 3.5\times10^{37}(D/7.6kpc)^2$erg s^{-1}. We also find that the low-state radio spectrum appeared consistent regardless of X-ray hardness, implying a connection between jet quenching and mass accretion rate in 4U 1820–30, possibly related to the properties of the inner accretion disk or boundary layer. This work has been done in collaboration with T. D. Russell, N. Degenaar, J. van den Eijnden, et al.

Thermonuclear X-ray bursts from LMXB 4U 1636–536 observed with AstroSat

We report results obtained from the study of 12 thermonuclear X-ray bursts in 6 *AstroSat* observations of a neutron star X-ray binary and well-known X-ray burster, 4U 1636–536. Burst oscillations at $\sim$581 Hz are observed with 4–5σ confidence in three of these X-ray bursts. The rising phase burst oscillations show a decreasing trend of the fractional rms amplitude at 3σ confidence, by far the strongest evidence of thermonuclear flame spreading observed with *AstroSat*. During the initial 0.25 second of the rise a very high value (34.0$\pm$6.7%) is observed. The concave shape of the fractional amplitude profile provides a strong evidence of latitude-dependent flame speeds, possibly due to the effects of the Coriolis force. We observe decay phase oscillations with amplitudes comparable to that observed during the rising phase, plausibly due to the combined effect of both surface modes as well as the cooling wake. The Doppler shifts due to the rapid rotation of the neutron star might cause hard pulses to precede the soft pulses, resulting in a soft lag. The distance to the source estimated using the PRE bursts is consistent with the known value of $\sim$ 6 kpc. This work has been done in collaboration with Pinaki Roy and Aditya S. Mondal.

Piyali Bhar

Charged gravastar model in $f(T)$ gravity admitting conformal motion

In this paper, model of charged gravastar under $f(T)$ modified gravity is obtained. The model has been explored by taking the diagonal tetrad field of static spacetime together with electric charge. To solve the Einstein-Maxwell field equations, along with $f(T)$ gravity, we assume the existence of a conformal Killing vector which relates between geometry and matter through the Einstein-Maxwell field equations by an inheritance symmetry. We study several cases of interest to explore physically valid features of the solutions. Some physical properties of the model are discussed and we match our interior spacetime to the exterior ReissnerNordström spacetime in presence of thin shell. This work has been done in collaboration with Pramit Rej.

Relativistic compact stars in Tolman spacetime via an anisotropic approach

In this present work, we have obtained a singularity-free spherically symmetric stellar model with anisotropic pressure in the background of Einsteins general theory of relativity. The Einsteins field equations have been solved by exploiting Tolman ansatz[Richard C Tolman, Phys. Rev. 55:364, 1939] in (3+1)-dimensional space-time. Using observed values of mass and radius of the compact star PSR J1903+327, we have calculated the numerical values of all the constants from the boundary conditions. All the physical characteristics of the proposed model have been discussed both analytically and graphically. The new exact solution satisfies all the physical criteria for a realistic compact star. The matter variables are regular and well behaved throughout the stellar structure. Constraints on model parameters have been obtained. All the energy conditions are verified with the help of graphical representation. The stability condition of the present model has been described through different testings.

This work has been done in collaboration with Pramit Rej, P. Mafa Takisa and M. Zubair

Naseer I. Bhat

Model-independent redshift estimation of BL Lac objects through very high energy observations

The very-high-energy (VHE) gamma-ray spectral indices of blazars show a strong correlation with the source redshift. The absence of any such correlation in low-energy gamma-rays and X-rays indicates the presence of extragalactic background light (EBL)-induced absorption of VHE gamma-rays. By employing a linear regression analysis, this observational feature of blazars is used to constrain the redshifts of BL Lac objects that were unknown/uncertain earlier. In addition, we compare the observed VHE spectral indexredshift correlation with those predicted from commonly adopted EBL models. Our study highlights the deviation of EBLmodel-based predictions from observations, especially at high redshifts. This work has been done in collaboration with Zahoor Malik,Sundar Sahayanathan , Zahir shah,Aqqib Manzoor, and Nilay Bhat,

Subhra Bhattacharya

Revisiting the evolving Lorentzian wormhole: a general perspective

Wormholes can be described as geometrical structures in space and time that can serve as connection between distant regions of the universe. Mathematically, general wormholes can be defined both on stationary as well as on dynamic line elements. However, general relativistic and evolving Lorentzian wormholes are less studied than their static wormhole counterpart. Accordingly, in this work we shall focus on some evolving wormhole geometries. Starting from a general class of spherically symmetric line element supporting wormhole geometries, we shall use the Einstein's field equations to develop viable astatic wormhole solutions. We will also discuss various evolving wormhole solutions together with their physical significance, properties and throat energy conditions. We claim that the method discussed in this work shall be applicable for developing wormhole solutions corresponding to any general Lorentzian wormhole metric. This work has been done in collaboration with Tanwi Bandyopadhyay.

Ritabrata Biswas

Viscous dark energy accretion activities : sonic speed, angular momentum and Mach number studies.

In this present article, we study different accretion properties regarding viscous accretion of dark energy. Modified Chaplygin gas is chosen as the dark energy candidate. Viscosity is encountered with the help of ShakuraSunyaev viscosity parameter. We study sonic speed vs radial distance curves. We compare between adiabatic and dark energy dominated cases and follow that sonic speed falls as we go nearer to the central gravitating object. As viscosity is imposed, a threshold drop in accretion sonic speed is followed. Average rate of fall in accretion sonic speed is increased with black holes spin. This is signifying that this kind of accretion is weakening the overall matter/energy infall. Specific angular momentum to Keplerian angular momentum ratio is found to fall as we go far from the black hole. Accretion Mach number turns high as we go towards the inner region and high wind Mach number is not allowed as we are going out. Combining, we conclude that the system weakens the feeding process of accretion. This work has been done in collaboration with Sandip Dutta, Promila Biswas.

Thermodynamic and geometrothermodynamic studies of charged black holes sitting in string theory: Stability analysis.

A particular type of charged black holes is chosen, based on an action obtained from string theory. This theory predicts the existence of such black holes. Thermodynamic properties of such kinds of black holes are studied. As conjectured earlier, for the dilaton-Maxwell field coupling constant $a = 0$, the behaviors of the thermodynamic parameters (T, S, F, H and G) are found to resemble with those of the ReissnerNordstrm black hole. The geometrothermodynamics of the aforesaid black hole is studied and the Ricci scalar of the Ruppeiner metric is graphically examined for different values of the parameter a. Finally, the parameters as well as the P-V criticality with different equations for nonzero values of a are analyzed. Their deviations from the case of ReissnerNordstrm black hole are noted with care. Furthermore, the stability of the black hole is studied by computing the specific heat and analyzing it graphically. This work has been done in collaboration with Amritendu Haldar,and Buddhadeb Ghosh

Koushik Chakraborty

Study of compact object with anisotropic matter distribution to follow a linear pressure-density relationship

We present a model of compact astrophysical object under General Theory of Relativity using the anisotropic extension of Tolman IV solution. The anisotropy function, derived from the model, remains well behaved throughout the interior of the star. The model satises several necessary con ditions for a physically realistic compact star. Physical viability of the model is veried specically by plugging in the estimated parameter values of the Low Mass X-ray Binary (LMXB) candidate 4U 160852. Our stability analysis of this star, by using various criteria for stability, provides satisfactory results. In connection to anisotropy, we compute the Tidal Love Number (TLN) for the compact stellar model and compare the calculated values with existing literature. This work has been done in collaboration with Shyam Das, Lipi Baskey, and Saibal Ray.

Subenoy Chakraborty

Is warm inflation quasi-stable

The present work deals with a non-equilibrium thermodynamics that is associated with the scenario of warm inflation. The premise is that an adiabatic radiation production process holds exactly i.e. the radiation dilution is exactly counterbalanced by a dissipation term. Under this hypothesis, it is found that radiation particle number, temperature, radiation energy density and pressure are all conserved – a contradiction to the very nature of the warm inflation dynamics. However, such exact adiabatic radiation production process never happens in any realistic analysis of warm inflation. In the slow roll approximation this holds at best at the zeroth order. Finally it is shown that a variable cosmological constant may accommodate the quasi-stable process in warm inflation with non-equilibrium thermodynamic description. This work has been done in collaboration with Akash Bose.

Quantum cosmology with symmetry analysis for quintom dark energy model

Quantum cosmology with quintom dark energy model has been investigated in the present work using symmetry analysis of the underlying physical system. In the background of the flat FLRW model quintom cosmological model has been studied using Noether symmetry and appropriate conserved charge is obtained. The Wheeler-DeWitt (WD) equation is constructed on the minisuperspace and solutions are obtained using conserved charge. This work has been done in collaboration with Sourav Dutta, and Muthusamy Lakshmanan.

Nand K. Chakradhari

A type Ia Supernova explosion similar to Super Chandrasekhar event

We present optical photometric and spectroscopic studies of type Ia supernova PSN J0910 + 5003 in UGC 4812. The observations range from -10 to +114 d relative to maximum light in B band (JD = 245 7347.0 ± 0.6). PSN J0910 + 5003 exhibits properties similar to the super-Chandrasekhar / 09dclike SNe Ia. Compared to the normal SNe Ia, its light curves are very broad. The decline rate parameter is estimated as $\Delta m_{15}(B)_{\rm true} = 0.70 \pm 0.05$ similar to the values obtained for most 09dc-like SNe Ia, e.g., 2006gz/09dc/07if and ASASSN-15pz. The absolute magnitudes at maximum in B and V bands are estimated as -19.44 ± 0.20 mag and -19.48 ± 0.20 mag, respectively. From the peak bolometric luminosity ($\log L_{\rm bol}^{\rm max} = 43.25 \pm 0.06$ erg/s), the mass of ^{56}Ni synthesized in the explosion is estimated as 0.64 ± 0.09 $M_\odot$. Early spectra of PSN J0910+5003 closely match with those of 09dc-like SNe Ia. The C II lines usually seen in super-Chandrasekhar events are also detected. Photospheric velocity evolution of PSN J0910+5003 is similar to SN 2006gz. This is a collaborative work of Shrutika Tiwari, D.K. Sahu and G. C. Anupama.

Study of chemically peculiar stars - I. High-resolution spectroscopy and K2 photometry of Am stars in the region of M44

We present a study based on the high-resolution spectroscopy and K2 space photometry of five chemically peculiar stars in the region of the open cluster M44. The analysis of the high-precision photometric K2 data reveals that the light variations in HD7 3045 and HD 76310 are rotational in nature and caused by spots or cloud-like co-rotating structures, which are non-stationary and short-lived. The time-resolved radial velocity measurements, in combination with the K2 photometry, confirm that HD73045 does not show any periodic variability on time-scales shorter than 1.3d, contrary to previous reports in the literature.

In addition to these new rotational variables, we discovered a new heartbeat system, HD 73619, where no pulsational signatures are seen. The spectroscopic and spectropolarimetric analyses indicate that HD 73619 belongs to the peculiar Am class, with either a weak or no magnetic field, considering the 200-G detection limit of our study. The least-squares deconvolution profiles for HD76310 indicate a complex structure in its spectra, suggesting that this star is either part of a binary system or surrounded by a cloud shell. When placed in the HertzsprungRussell diagram, all studied stars are evolved from the main sequence and situated in the δ Scuti instability strip. This work is relevant for further detailed studies of chemically peculiar stars, for example on inhomogeneities (including spots) in the absence of magnetic fields and the origin of the pulsational variability in heartbeat systems. This work was carried out in collaboration with Santosh Joshi, Otto Trust, et al.

Hum Chand

A comparative study of the physical properties for a representative sample of Narrow and Broad-line Seyfert galaxies

We present a comparative study of the physical properties of a homogeneous sample of 144 Narrow line Seyfert 1 (NLSy1) and 117 Broad-line Seyfert 1 (BLSy1) galaxies. These two samples are in a similar luminosity and redshift range and have optical spectra available in the 16^{th} data release of Sloan Digital Sky Survey (SDSS-DR16) and X-ray spectra in either XMM-NEWTON or ROSAT. Direct correlation analysis and a Principal Component Analysis (PCA) have been performed using ten observational and physical parameters obtained by fitting the optical spectra and the soft X-ray photon indices as another parameter. We confirm that the established correlations for the general quasar population hold for both types of galaxies in this sample despite significant differences in the physical properties. We characterize the sample also using the line shape parameters, namely the asymmetry and kurtosis indices. We find that the fraction of NLSy1 galaxies showing outflow signatures, characterized by blue asymmetries, is higher by a factor of about 3 compared to the corresponding fraction in BLSy1 galaxies. The presence of high iron content in the broad-line region of NLSy1 galaxies in conjunction with higher Eddington ratios can be the possible reason behind this phenomenon. We also explore the possibility of using asymmetry in the emission lines as a tracer of outflows in the inner regions of Active Galactic Nuclei. The PCA results point to the NLSy1 and BLSy1 galaxies occupying different parameter spaces, which challenges the notion that NLSy1 galaxies are a subclass of BLSy1 galaxies. This work has been done in collaboration with Vivek K. Jha,Vineet Ojha, Amitesh Omar and Shantanu Rastogi.

Constraining the ratio of median pixel optical depth profile around $z \sim 4$ quasars using the longitudinal proximity effect

We present a detailed study of the longitudinal proximity effect using a sample of 85 quasars spanning an emission redshift range of $3.5 \leq z_{em} \leq 4.5$ and Lyman continuum luminosity (L_{912}) ranging from $1.06{\times}10^{31}$ to $2.24{\times}10^{32}$ erg s^{-1} Hz^{-1}. We use the high-quality spectra of these quasars obtained at a spectral resolution of $R \sim 5100$ and S/N ~ 30 using X-SHOOTER spectrograph mounted on the Very Large Telescope (VLT). In our analysis, we compared the transmitted flux and pixel optical depth of the absorption originating from the vicinity of quasars to those from the general intergalactic medium by using a redshift matched control sample. The longitudinal proximity effect is found up to $r \leq 12$ Mpc (proper) from quasars. By appropriately scaling up the pixel optical depth in the vicinity of quasars to account for the excess ionization by quasars, we constrain the ratio of median optical depth in the vicinity of the quasar to that of the IGM ($R_\tau(r)$). The $R_\tau(r)$ is found to be significantly higher than unity up to 6 Mpc from the quasar with a typical radial profile of the form $R_\tau(r) = 1 + A \times exp(-r/r_0)$ with $A = 9.16 \pm 0.68$ and $r_0 = 1.27 \pm 0.08$ Mpc. The integrated value of the scaled pixel optical depth over the radial bin of 0-6 Mpc is found to be higher by a factor of 2.55 ± 0.17 than the corresponding integrated value of the median pixel optical depth of the IGM. We also found $R_\tau(r)$ to be luminosity dependent. This work has been done in collaboration with Priyanka Jalan, Raghunatha Srianand.

Ramesh Chandra

Filament eruption driving EUV Loop contraction and then expansion above a stable filament

We analyze the observations of EUV loop evolution associated with the filament eruption located at the border of an active region (AR). The event SOL2013-03-16T14:00 was observed with a large difference in view point by the Solar Dynamics Observatory and Solar Terrestrial Relations Observatory. The filament height is fitted with the sum of a linear and exponential function. These two phases point to different physical mechanisms such as tethercutting reconnection and a magnetic instability. While no X-ray emission is reported, this event presents classical eruption features like separation of double ribbons and the growth of flare loops. We report the migration of the southern foot of the erupting filament flux rope due to the interchange reconnection with encountered magnetic loops of a neighboring AR. Parallel to the erupting filament, a stable filament remains in the core of the AR. The specificity of this eruption is that coronal loops, located above the nearly joining ends of the two filaments, first contract in phase, then expand and reach a new stable configuration close to the one present at the eruption onset. Both contraction and expansion phases last around 20 minutes. The main difference with previous cases is that the PIL bent about 180 around the end of the erupting filament because the magnetic configuration is at least tripolar. These observations are challenging for models that interpreted previous cases of loop contraction within a bipolar configuration. New simulations are required to broaden the complexity of the configurations studied. This work has been done in collaboration with P. Demoulin, P. Devi, R. Joshi, and B. Schmieder.

Fine Structures of an EUV Wave Event from Multi-viewpoint Observations

In this study, we investigate an extreme ultraviolet (EUV) wave event on 2010 February 11, which occurred as a limb event from the Earth viewpoint and a disk event from the Solar Terrestrial Relations Observatory-Behind viewpoint. We use the data obtained by the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory in various EUV channels. The EUV wave event was launched by a partial prominence eruption. Compared with some EUV wave events in previous works, this EUV wave event contains a faster wave with a speed of $\sim$445 $\hat{A}$ $\pm$ 6 km s^{-1}, which we call a coronal Moreton wave, and a slower wave with a speed of $\sim$298 $\hat{A}$ $\pm$ 5 km s^{-1}, which we call the Extreme Ultraviolet Imaging Telescope (EIT) wave. The coronal Moreton wave is identified as a fast-mode wave and the EIT wave is identified as an apparent propagation due to successive field-line stretching. We also observe a stationary front associated with the fast-mode EUV wave. This stationary front is explained as mode conversion This work has been done in collaboration with P. F. Chen, P. Devi, R. Joshi, B. Schmieder, Y. J. Moon,and W. Uddin.

Suresh Chandra

Investigation of hydrogen peroxide (H_2O_2) in the interstellar medium

In view of the important role of hydrogen peroxide (H_2O_2) in the chemistry of ozone layer in troposphere, and as an oxidizer on the planet Mars, its investigation has been carried out from time to time. It has been detected in the cold environment of a star-forming region towards ρ Oph A. Following the selection rules, in the ground vibrational state, its ro-torsional levels may be classified into four distinct groups. Using the spectroscopic information (rotational and centrifugal distortion constants, and electric dipole moment), we have calculated energies of the lower 50 levels of each group, and the radiative transition probabilities for the transitions between the levels. Using these radiative transition probabilities along with the collisional rate coefficients (obtained with the help of a scaling law) we have solved, for each group, a set of 50 statistical equilibrium equations coupled with the equations of radiative transfer and have found 16 lines showing anomalous absorption. In addition to 4 detected lines, 24 lines are found to show emission feature. All these lines may play a significant role for the identification of H_2O_2 in the interstellar medium.

Suggestion for the search of diisocyanomethane ($CNCH_2NC$) in the cosmic object: Potential spectral lines

Finding several molecules having cyanide group (-C≡N) and isocyanide group (-N≡C), scientists searching for life in the universe, are interested in the molecules having two cyanide or isocyanide groups. Diisocyanomethane ($CNCH_2NC$) having two isocyano groups is an interesting candidate for the astronomers, though it has not been detected in any cosmic object. However, three organic isocyanides (HNC, CH_3NC, HCCNC) have been found in the interstellar medium (ISM). Submillimeter wave spectrum of $CNCH_2NC$ is analyzed by spectroscopists, so that it could be searched in the ISM. For searching $CNCH_2NC$ in a cosmic object, information about its strong spectral lines is essentially required. For that, in our investigation, the rotational levels of $CNCH_2NC$ can be classified into two species. The energies of lower 250 rotational levels up to 108 cm^{-1}, in the ground vibrational state, and the radiative transition probabilities for rotational transitions in each species are calculated by using the values of rotational and centrifugal distortion constants along with the electric dipole moment. A set of statistical equilibrium equations coupled with the equations of radiative transfer is solved by using the radiative transition probabilities and the scaled values of collisional rate coefficients as input data. For each species, we have found two transitions showing emission feature and four transitions showing anomalous absorption. These 12 transitions may help in the detection of $CNCH_2NC$ in a cosmic object.

Surajit Chattopadhyay

The barrow holographic dark energy based reconstruction of $f(R)$ gravity and cosmology with Nojiri-Odintsov cutoff

In the work, carried out with Amrita Sarkar, we have considered Barrow holographic dark energy (BHDE) proposed in *Phys. Rev. D* **102**, 123525 (2020) as a special case of more generalized version of Nojiri-Odintsov holographic dark energy (NHDE) proposed in *General Relativity and Gravitation*, **38(8)**, pp.1285-1304 and also reconstructed $f(R)$ gravity with BHDE as the form of background evolution. We have demonstrated a reconstruction scheme for Barrow holographic dark energy considering power-law form of scale factor. Considering the fact that the Barrow holographic dark energy (BHDE) possesses usual holographic dark energy as a limit in the $\Delta = 0$ case we have attempted to demonstrate its reconstruction scheme in non-interacting scenario for $\Delta \neq 0$. We have derived an expression for the reconstructed equation of state parameter by reconstructing the pressure of BHDE, whose density is given by $\rho_D = CR_h^{2(\Delta-1)}$, where R_h is the future event horizon satisfying $\dot{R}_h = HR_h - 1$. The reconstructed pressure has been presented and plotted. It has been apparent that in case of non-interacting Barrow HDE, the reconstructed p_D significantly depends upon Δ. With increase in Δ between 0 and 1, negative pressure p_D has been found to be increasing. However as $\Delta \to 0$, the reconstructed $p_D \approx 0$ and for $\Delta \to 1$ the reconstructed p_D has been found to be negative. With evolution of universe i.e with increase of t, p_D has been been found to be having an increasing pattern. It has also been observed that with increase in Δ, the magnitude of p_D tends to be negative. Subsequently, the reconstructed EoS w_D has been obtained. It has been observed that in the case of BHDE reconstructed $f(R)$ gravity the equation of state can have a transition from quintessence to phantom. In a particular case of reconstruction, possibility of Little Rip singularity has been observed. Finally, the generalized second law of thermodynamics has been found to be valid under this reconstruction scheme. This work has been done in Collaboration with Amrita Sarkar.

Viscous generalised Chaplygin Gas under the purview of $f(T)$ gravity and the model assessment through probabilistic information theory

In this study, carried out with Sanghati Saha, we have demonstrated a reconstruction scheme for GCG in viscous as well as non viscous cases. In both the cases the GCG has been considered to be interacting with pressureless dark matter with interaction term Q proportional to ρ_c and ρ_m in non-viscous and viscous cases respectively. The bulk viscous pressure Π has been chosen as a function of Hubble parameter H in the form $\Pi = -3H\xi$. The conservation equation has been reframed according to the choice of interaction term ad Π and the reconstructed ρ_c, the density of GCG has been obtained for non-viscous and viscous scenarios. Firstly, we attempted to reconstruct GCG in an interacting scenario and without introducing bulk viscosity. Furthermore, in the first case, i.e. non-viscous interacting scenario, we do not stick to any specific choice of scale factor. Instead, by taking interaction term $Q = -3H\delta\rho_c$ we reframe the conservation equation with the scale factor a as the independent variable and solve this differential equation for ρ_c. The reconstructed ρ_c and the reconstructed EoS parameter are plotted against redshift $z = a^{-1} - 1$ and it that the reconstructed w_c is crossing the phantom boundary at $z \approxeq -0.09$. In the above two figures, the choice of the parameters are $\rho_{m0} = 0.32$, $\alpha = 0.09$, $a_0 = 0.32$. Moreover, $B = 16$ and $C_1 = 1$. The blue, orange and green lines correspond to $\delta = 0.08$, 0.06 and 0.04 respectively. It is observed that for higher values of δ the phantom boundary is crossed earlier than that for the lower values. Finally, the model is identified as quintom. Finally, we have explored the model through statistical analysis of Observational $H(z)$ Data From Luminous Red Galaxies of Sloan Digital Sky Survey Data Release Seven (SDSS DR7). Through Hypothesis testing we have generated a functional relationship between H and

z and we have observed that the reconstructed EoS parameter has a strong correlation with z and $H(z)$. Using scatter plot matrix we have demonstrated the relationship between the reconstructed EoS parameter and $(z, H(z))$. Best fit linear and non-linear regressions and the residuals have been pictorially demonstrated and it has been observed that the residuals do not follow normal distribution. With this indication of departure from symmetry we have incorporated entropy maximization principles to quantify the uncertainty in terms of Shannon entropy. This approach has revealed that the degree of uncertainty is reducing with the evolution of the universe. It has further shown that the reconstructed viscous GCG in $f(T)$ gravity framework can work as an unifying model for early and late time universe. This results has further been supplemented by clustering through Gaussian Mixture Model.

Bhag Chand Chauhan

Scalar Dark Matter in A_4 based texture one-zero neutrino mass model within Inverse Seesaw Mechanism

In this paper, we present a model based on A_4 discrete flavor symmetry implementing inverse and type-II seesaw mechanisms to have LHC accessible TeV scale right-handed neutrino mass and texture one-zero in the resulting Majorana neutrino mass matrix, respectively. We investigate neutrino and dark matter sectors of the model. Non-Abelian discrete A_4 symmetry spontaneously breaks into Z_2 subgroup and hence provide stable dark matter candidate. To constrain the Yukawa Lagrangian of our model, we imposed Z_2', Z_3 and Z_4 cyclic symmetries in addition to the A_4 flavor symmetry. In this work we used the recently updated data on cosmological parameters from PLANCK 2018. For the dark matter candidate mass around 45 GeV-55 GeV, we obtain the mediator particle mass(right-handed neutrinos) ranging from 138 GeV to 155 GeV. The Yukawa couplings is found to be in the range 0.995-1 to have observed relic abundance of dark matter. We, further, obtain inverse ($X \equiv \frac{F^2 n}{z^2}$) and type-II ($X' \equiv f_1 v_{\Delta_1}$) seesaw contributions to $0\nu\beta\beta$ decay amplitude $|M_{ee}|$, while model being consistent with low energy experimental constraints. In particular, we emphasize that type-II seesaw contribution to $|M_{ee}|$ is large as compared to inverse seesaw contribution for normally ordered(NO) neutrino masses. This work has been done in collaboration with Rishu Verma, Monal Kashav,and Surender Verma.

Scotogenesis in hybrid textures of neutrino mass matrix and neutrinoless double beta decay

We study the connection between dark matter (DM) and neutrinoless double beta ($0\nu\beta\beta$) decay in a scotogenic model with hybrid texture in the neutrino mass matrix. Characteristically, the framework allows to write all the non-zero elements of the mass matrix proportional to effective Majorana mass $|M_{ee}|$. The overall scale of the neutrino mass is found to be governed by non-zero $|M_{ee}|$. We have obtained interesting correlations of relic density of DM(Ωh^2) with DM mass M_1 and $|M_{ee}|$. Using experimental value of DM relic density(Ωh^2), the DM mass M_1, is found to be $\mathcal{O}$(1TeV) which is within reach of collider experiments. Specifically, for all five hybrid textures, the range of upper bound on DM mass M_1 is found to be (2.27-5.31)TeV. Another interesting feature of the model is the existence of lower bound on $|M_{ee}|$ for all allowed hybrid textures except texture T_5 which can be probed in current and future $0\nu\beta\beta$ decay experiments. With high sensitivities, these experiments shall establish the theoretical status of the proposed model. For example, the non-observation of $0\nu\beta\beta$ decay down to the sensitivity $\mathcal{O}$(0.03)eV will refute T_3 hybrid texture. This work has been done in collaboration with Ankush, Monal Kashav, and Surender Verma

Himadri S. Das

The relative orientation between local magnetic eld and Galactic plane in low latitude dark clouds

In this work, we study the magnetic field morphology of selected star-forming clouds spread over the galactic latitude (b) range, $-10°$ to $10°$. The polarimetric observation of clouds CB24, CB27 and CB188 are conducted to study the magnetic field geometry of those clouds using the 104-cm Sampurnanand Telescope (ST) located at ARIES, Manora Peak, Nainital, India. These observations are combined with those of 14 further low latitude clouds available in the literature. Most of these clouds are located within a distance range 140 to 500 pc except for CB3 (~2500 pc), CB34 (~1500 pc), CB39 (~1500 pc) and CB60 (~1500 pc). Analyzing the polarimetric data of 17 clouds, we find that the alignment between the envelope magnetic field (θ_B^{env}) and Galactic plane (θ_{GP}) of the low-latitude clouds varies with their galactic longitudes (l). We observe a strong correlation between the longitude (l) and the offset ($\theta_{off} = |\theta_B^{env} - \theta_{GP}|$) which shows that θ_B^{env} is parallel to the Galactic plane (GP) when the clouds are situated in the region, $115° < l < 250°$. However, θ_B^{env}

has its own local deflection irrespective of the orientation of θ_{GP} when the clouds are at $l < 100°$ and $l > 250°$. To check the consistency of our results, the stellar polarization data available at Heiles (2000) catalogue are overlaid on DSS image of the clouds having mean polarization vector of field stars. The results are almost consistent with the Heiles data. A systematic discussion is presented in the paper. The effect of turbulence of the cloud is also studied which may play an important role in causing the misalignment phenomenon observed between θ_B^{env} and θ_{GP}. We have used *Herschel*[1] *SPIRE* 500 μm and *SCUBA* 850 μm dust continuum emission maps in our work to understand the density structure of the clouds. This work has been done in collaboration with A. M. Mazarbhuiya, and P. Halder.

Shyam Das

Anisotropic compact stars: Constraining model parameters to account for physical features of tidal Love numbers

In this paper, we develop a new class of models for a compact star with anisotropic stresses inside the matter distribution. By assuming a linear equation of state for the anisotropic matter composition of the star we solve the Einstein field equations. In our approach, for the interior solutions we use a particular form of the ansatz for the metric function g_rr . The exterior solution is assumed as the Schwarzschild metric and is joined with the interior metric obtained across the boundary of the star. These matching of the metrices along with the condition of the vanishing radial pressure at the boundary lead us to determine the model parameters. The physical acceptability of the solutions has verified by making use of the current estimated data available from the pulsar 4U 1608 52. Thereafter, assuming anisotropy due to tidal effects we calculate the Love numbers from our model and compare the results with the observed compact stars, viz. KS 1731260, 4U 160852, 4U 1724207, 4U 182030, SAX J1748.9 2021 and EXO 1745 268. The overall situation confirms physical viability of the proposed approach, which can shed new light on the interior of the compact relativistic objects. This work has been done in collaboration with Saibal Ray, Maxim Khlopov, K.K. Nandi, and B.K. Parida

[1]Herschel is an ESA space observatory with science instruments provided by European-led Principal Investigator consortia and with important participation from NASA.

Estimating tidal Love number of a class of compact stars

Tidal deformability of a star in the presence of an external tidal field provides an important avenue to our understanding about the structure and properties of neutron stars. The deformation of the star is characterized by the tidal Love number (TLN). In this paper, we propose a technique to measure the TLN of a particular class of compact stars. In particular, we analyze the impact of anisotropy and compactness on the TLN. This work has been done in collaboration with Bikram K. Parida, and Ranjan Sharma.

Sudipta Das

Growth of perturbations using Lambert W equation of state

Recently, a novel equation of state (EoS) parameter for dark energy has been introduced which deals with a special mathematical function, known as the Lambert W function. In this paper, we study the effect on the growth of perturbations for the Lambert W dark energy model. We perform the analysis for two different approaches. In the first case, we consider the universe to be filled with two different fluid components, namely, the baryonic matter component and the Lambert W dark energy component, while in the second case, we consider that there is a single fluid component in the universe whose equation of state parameter is described by the Lambert W function. We then compare the growth rates of Lambert W model with that for a standard CDM model as well as the CPL model. Our results indicate that the presence of Lambert W dynamical dark energy sector changes the growth rate and affects the matter fluctuations in the universe to a great extent. This work has been done in collaboration with Manisha Banerjee, Abdulla Al Mamon, Subhajit Saha and Kazuharu Bamba

Barrow holographic dark energy in a nonflat universe

We construct Barrow holographic dark energy in the case of nonflat universe. In particular, considering closed and open spatial geometry we extract the differential equations that determine the evolution of the dark-energy density parameter, and we provide the analytical expression for the corresponding dark energy equation-of-state parameter. We show that the scenario can describe the thermal history of the universe, with the sequence of matter and dark energy epochs. Comparing to the flat case, where the phantom regime is obtained for relative large Barrow exponents, the incorporation of positive curvature leads the universe into the phantom regime for significantly smaller values. Additionally, in the case of negative curvature we find a reversed behavior, namely for increased Barrow exponent we acquire algebraically higher dark energy equation-of-state parameters. Furthermore, we confront the scenario with Hubble parameter measurements and supernova type Ia data. Hence, the incorporation of slightly non-flat spatial geometry to Barrow holographic dark energy improves the phenomenology while keeping the new Barrow exponent to smaller values. This work has been done in collaboration with Priyanka Adhikary,and Spyros Basilakos.

Partha Sarathi Debnath

Cosmological models in R^2 gravity with hybrid expansion law

In the present paper evolution of a Friedmann-Robertson Walker universe is studied in a Higher derivative theory of gravity. The relativistic solutions admitting hybrid expansion law of the universe are explored here. Hybrid expansion law is a general form of scale factor from which one can recover both the power-law expansion and exponential expansion as a special case. The hybrid expansion law is interesting as it addresses the early deceleration phase and present accelerating phase satisfactorily. It is found that an Inflationary scenario with hybrid expansion law is permitted in the R^2 gravity fairly well. We consider universe filled with cosmic fluid that describes by an equation of state parameter which varies with time. Consequently we anlyze the time variation of energy density parameter, cosmic pressure, equation of state parameter, deceleration parameter and jerk parameter in the cosmological model. The constraints of the models parameters imposed by the cosmological observational data set are determined. The present value of the deceleration parameter (q), equation of state parameter and the epoch at which the transition of decelerated phase to accelerated phase are estimated. In the higher derivative theory we obtain some new and interesting cosmological solutions relevant for building cosmological models. This work has been done in collaboration with Bikash Chandra Paul.

Ujjal Debnath

Charged Gravastars in Rastall-Rainbow Gravity

We have assumed the spherically symmetric stellar system in the contexts of Rastall-Rainbow gravity theory in the presence of isotropic fluid source with electro-magnetic field. Einstein-Maxwell's field equations have been written in the framework of Rastall-Rainbow gravity. Next, we have discussed the geometry of charged gravastar model. The gravastar consists of three regions: interior region, thin shell region, and exterior region. In the interior region, the gravastar follows the equation of state (EoS) $p = -\rho$, and we have found the solutions of all physical quantities like energy density, pressure, electric field, charge density, gravitational mass, and metric coefficients. In the exterior region, we have obtained the exterior Riessner-Nordstrom solution for vacuum model ($p = \rho = 0$). Since in the shell region, the fluid source follows the EoS $p = \rho$ (ultra-stiff fluid) and the thickness of the shell of the gravastar is infinitesimal, so by the approximation h ($\equiv A^{-1}$) $\ll 1$, we have found the analytical solutions within the thin shell. The physical quantities like the proper length of the thin shell, entropy, and energy content inside the thin shell of the charged gravastar have been computed, and we have shown that they are directly proportional to the proper thickness of the shell (ϵ) due to the approximation $\epsilon \ll 1$. The physical parameters significantly depend on the Rastall parameter and Rainbow function. Next, we have studied the matching between the surfaces of interior and exterior regions of the charged gravastar, and using the matching conditions, the surface energy density and the surface pressure have been obtained. Also, the equation of state parameter on the surface, mass of the thin shell, mass of the gravastar have been calculated. Finally, we have explored the stability of the charged gravastar in Rastall-Rainbow gravity.

Observational Data Analysis for Generalized Cosmic Chaplygin Gas in the Background of Brans-Dicke Theory

We have considered the generalized cosmic Chaplygin gas (GCCG) in the background of Brans-Dicke (BD) theory and also assumed that the Universe filled in GCCG, dark matter, and radiation. To investigate the data fitting of model parameters, we have constrained the model using recent observations. Using χ^2 minimum test, the best fit values of the model parameters are determined by OHD+CMB+BAO+SNIa joint data analysis. We have drawn the contour figures for different confidence levels 1σ, 2σ and 3σ. To examine the viability of the GCCG model in BD theory, we have also determined △AIC and △BIC using the information criteria (AIC and BIC). Graphically, we have analyzed the natures of the equation of state parameter and deceleration parameter for our best fit values of model parameters. Also, we have studied the square speed of sound v_s^2 which lies in the interval $(0, 1)$ for expansion of the Universe. So our considered model is classically stable by considering the best fit values of the model parameters due to the data analysis.

Shantanu Desai

Variational Inference as an alternative to MCMC for parameter estimation and model selection

Most applications of Bayesian Inference for parameter estimation and model selection in astrophysics involve the use of Monte Carlo techniques such as Markov Chain Monte Carlo (MCMC) and nested sampling. However, these techniques are time consuming and their convergence to the posterior could be difficult to determine. In this work, we advocate Variational inference as an alternative to solve the above problems, and demonstrate its usefulness for parameter estimation and model selection in Astrophysics. Variational inference converts the inference problem into an optimization problem by approximating the posterior from a known family of distributions and using Kullback-Leibler divergence to characterize the difference. It takes advantage of fast optimization techniques, which make it ideal to deal with large datasets and makes it trivial to parallelize on a multicore platform. We also derive a new approximate evidence estimation based on variational posterior, and importance sampling technique called posterior weighted importance sampling for the calculation of evidence (PWISE), which is useful to perform Bayesian model selection. As a proof of principle, we apply variational inference to five different problems in astrophysics, where Monte Carlo techniques were previously used. These include assessment of significance of annual modulation in the COSINE-100 dark matter experiment, measuring exoplanet orbital parameters from radial velocity data, tests of periodicities in measurements of Newton's constant G, assessing the significance of a turnover in the spectral lag data of GRB 160625B and estimating the mass of a galaxy cluster using weak gravitational lensing. We find that variational inference is much faster than MCMC and nested sampling techniques for most of these problems while providing competitive results. All our analysis codes have been made publicly available This evaluation has been done in collaboration with Geetakrishnasai Gunapati, Anirudh Jain, and P.K. Srijith

A test of constancy of dark matter halo surface density and radial acceleration relation in relaxed galaxy groups

The dark matter halo surface density, given by the product of the dark matter core radius (r_c) and core density (ρ_c) has been shown to be a constant for a wide range of isolated galaxy systems. Here, we carry out a test of this *ansatz* using a sample of 17 relaxed galaxy groups observed using Chandra and XMM-Newton, as an extension of our previous analysis with galaxy clusters. We find that $\rho_c \propto r_c^{-1.35^{+0.16}_{-0.17}}$, with an intrinsic scatter of about 27.3%, which is about 1.5 times larger than that seen for galaxy clusters. Our results thereby indicate that the surface density is discrepant with respect to scale invariance by about 2σ, and its value is about four times greater than that for galaxies. Therefore, the elevated values of the halo surface density for groups and clusters indicate that the surface density cannot be a universal constant for all dark matter dominated systems. Furthermore, we also implement a test of the radial acceleration relation for this group sample. We find that the residual scatter in the radial acceleration relation is about 0.32 dex and a factor of three larger than that obtained using galaxy clusters. The acceleration scale which we obtain is in-between that seen for galaxies and clusters. This work has been done in collaboration with Gopika K.

Vijayakumar H. Doddamani

Magnetic Imprints of Eruptive and Noneruptive Solar Flares as Observed by Solar Dynamics Observatory

The abrupt and permanent changes of the photospheric magnetic field in the localized regions of active regions during solar flares, called magnetic imprints (MIs), have been observed for nearly the past three decades. The well-known coronal implosion model is assumed to explain such flare-associated changes but the complete physical understanding is still missing and debatable. In this study, we made a systematic analysis of flare-related changes of the photospheric magnetic field during 21 flares (14 eruptive and seven noneruptive) using the 135 s cadence vector magnetogram data obtained from the Helioseismic and Magnetic Imager. The MI regions for eruptive flares are found to be strongly localized, whereas the majority of noneruptive events ($> 70\%$) have scattered imprint regions. To quantify the strength of the MIs, we derived the integrated change of horizontal field and the total change of Lorentz force over an area. These quantities correlate well with the flare strength, irrespective of whether flares are eruptive or not, or have a short or long duration. Further, the free energy (FE), determined from virial theorem estimates, exhibits a statistically significant downward trend that starts around the flare time and is observed in the majority of flares. The change of FE during flares does not depend on eruptivity but has a strong positive correlation ($\approx$ 0.8) with the Lorentz force change, indicating that part of the FE released would penetrate the photosphere. While these results strongly favor the idea of significant feedback from the corona on the photospheric magnetic field, the characteristics of MIs are quite indistinguishable from flares being eruptive or not. This study has been done in collaboration with N. Vasantharaju1, P. Vemareddy, and B. Ravindra1.

Jibitesh Dutta

Background evolution and growth of structures in interacting dark energy scenarios through dynamical system analysis

We apply the formalism of dynamical system analysis to investigate the evolution of interacting dark energy scenarios at the background and perturbation levels in a unified way. Since the resulting dynamical system contains the extra perturbation variable related to the matter overdensity, the critical points of the background analysis split, corresponding to the different behavior of matter perturbations, and hence to stability properties. From the combined analysis, we find critical points that describe the non-accelerating matter-dominated epoch with the correct growth of matter structure, and the fact that they are saddle provides the natural exist from this phase. Furthermore, we find stable attractors at late times corresponding to a dark energy-dominated accelerated solution with constant matter perturbations, as required by observations. Thus, interacting cosmology can describe the matter and dark energy epochs correctly, both at the background and perturbation levels, and since this is not possible in standard, i.e., non-interacting quintessence, it reveals the crucial effect of the interaction. This study has been done in collaboration with Wompherdeiki Khyllep, Spyros Basilakos,and Emmanuel N. Saridakis.

Cosmological solutions and growth index of matter perturbations in $f(Q)$ gravity

The present work studies one of Einstein's alternative formulations based on the non-metricity scalar Q generalized as $f(Q)$ theory. More specifically, we consider the power-law form of $f(Q)$ gravity i.e. $f(Q) = Q + \alpha\, Q^n$. Here, we analyze the behavior of the cosmological model at the background and perturbation level. At the background level, the effective evolution of the model is the same as that of the ΛCDM for $|n| < 1$. Interestingly, the geometric component of the theory solely determined the late-time acceleration of the Universe. We also examine the integrability of the model by employing the method of singularity analysis. In particular, we find the conditions under which field equations pass the Painlevé test and hence possess the Painlevé property. While the equations pass the Painlevé test in the presence of dust for any value of n, the test is valid after the addition of radiation fluid only for $n < 1$. Finally, at the perturbation level, the behavior of matter growth index signifies a deviation of the model from the ΛCDM even for $|n| < 1$.

This study has been done in collaboration with Wompherdeiki Khyllep, and Andronikos Paliathanasis

Abhik Ghosh

Demonstrating the Tapered Gridded Estimator (TGE) for the cosmological HI 21-cm power spectrum using 150MHz GMRT observations

We apply the Tapered Gridded Estimator (TGE) for estimating the cosmological 21-cm power spectrum from 150 MHz GMRT observations which corresponds to the neutral hydrogen (HI) at redshift $z = 8.28$. Here TGE is used to measure the Multi-frequency Angular Power Spectrum (MAPS) $C_\ell(\Delta\nu)$ first, from which we estimate the 21-cm power spectrum $P(k_\perp, k_\parallel)$. The data here are much too small for a detection, and the aim is to demonstrate the capabilities of the estimator. We find that the estimated power spectrum is consistent with the expected foreground and noise behaviour. This demonstrates that this estimator correctly estimates the noise bias and subtracts this out to yield an unbiased estimate of the power spectrum. More than 47% of the frequency channels had to be discarded from the data owing to radio-frequency interference, however the estimated power spectrum does not show any artifacts due to missing channels. Finally, we show that it is possible to suppress the foreground contribution by tapering the sky response at large angular separations from the phase center. We combine the k modes within a rectangular region in the 'EoR window' to obtain the spherically binned averaged dimensionless power spectra $\Delta^2(k)$ along with the statistical error σ associated with the measured $\Delta^2(k)$. The lowest k-bin yields $\Delta^2(k) = (61.47)^2\,\mathrm{K}^2$ at $k = 1.59\,\mathrm{Mpc}^{-1}$, with $\sigma = (27.40)^2\,\mathrm{K}^2$. We obtain a $2\,\sigma$ upper limit of $(72.66)^2\,\mathrm{K}^2$ on the mean squared HI 21-cm brightness temperature fluctuations at $k = 1.59\,\mathrm{Mpc}^{-1}$. This work has been done in collaboration with Srijita Pal, Somnath Bharadwaj, and Samir Choudhuri.

A numerical study of 21-cm signal suppression and noise increase in direction-dependent calibration of LOFAR data

We investigate systematic effects in direction dependent gain calibration in the context of the Low-Frequency Array (LOFAR) 21-cm Epoch of Reionization (EoR) experiment. The LOFAR EoR Key Science Project aims to detect the 21-cm signal of neutral hydrogen on interferometric baselines of $50 - 250\lambda$. We show that suppression of faint signals can effectively be avoided by calibrating these short baselines using only the longer baselines. However, this approach causes an excess variance on the short baselines due to small gain errors induced by overfitting during calibration. We apply a regularised expectation-maximisation algorithm with consensus optimisation (SAGECAL-CO) to real data with simulated signals to show that overfitting can be largely mitigated by penalising spectrally non-smooth gain solutions during calibration. This reduces the excess power with about a factor 4 in the simulations. Our results agree with earlier theoretical analysis of this bias-variance trade off and support the gain-calibration approach to the LOFAR 21-cm signal data.

This work has been done in collaboration with M.Mevius, F.Mertens, L.V.E.Koopmans, and A.R.Offringa1 et al.

Suman Ghosh

Generalised Ellis-Bronnikov wormholes embedded in warped braneworld background and energy conditions

Ellis-Bronnikov (EB) wormholes require violation of null energy conditions at the 'throat'. This problem was cured by a simple modification of the 'shape function', which introduces a new parameter $m \geq 2$ ($m = 2$ corresponds to the EB model). This leads to a generalised (GEB) version. In this work, we consider a model where the GEB wormhole geometry is embedded in a five dimensional warped background. We studied the status of all the energy conditions in detail for both EB and GEB embedding. We present our results analytically (wherever possible) and graphically. Remarkably, the presence of decaying warp factor leads to satisfaction of weak energy conditions even for the EB geometry, while the status of all the other energy conditions are improved compared to the four dimensional scenario. Besides inventing a new way to avoid the presence of exotic matter, in order to form a wormhole passage, our work reveals yet another advantage of having a warped extra dimension. This work has been done in collaboration with Vivek Sharma.

Sushant G. Ghosh

*Parameter estimation of hairy Kerr black holes from its shadow and constraints from M87**

The recently obtained hairy Kerr black holes, due to additional sources or surrounding fluid, like dark matter, with conserved energy-momentum tensor, have a deviation α and primary hair l_0, apart from rotation parameter a and mass M. In the wake of the *Event Horizon Telescope* (*EHT*) observations of the supermassive black hole M87*, a recent surge in interest in black hole shadows suggests comparing the black holes in general relativity (GR) and modified theories of gravity (MoG) to assess these models' differences. Motivated by this, we take on an extensive study of the rotating hairy Kerr black holes, which encompasses, in particular cases, the Kerr black hole ($\alpha = 0$). We investigate ergosphere and shadows of the black holes to infer that their size and shape are affected due to the l_0 and are found to harbour a richer chaotic structure. In particular, the hairy Kerr black holes possess smaller size but more distorted shadows when compared with Kerr black holes. We also estimate the parameters l_0 and a associated with hairy Kerr black holes using the shadow observables. The inferred circularity deviation $\Delta C \leq 0.1$ for the M87* black hole is satisfied, whereas shadow angular diameter $\theta_d = 42 \pm 3\mu as$, within 1σ region, for a given choice of α, places bounds on the parameters a and l_0. Interestingly, the shadow axial ratio obeying $1 < D_x \lesssim 4/3$ is in agreement with the *EHT* results and thus eventuates in the hairy Kerr black holes being suitable candidates for astrophysical black holes. This work has been done in collaboration with R.

Misba Afrin, and Rahul Kumar.

Strong gravitational lensing by rotating Simpson–Visser black holes

We investigate strong field gravitational lensing by rotating Simpson-Visser black hole, which has an additional parameter ($0 \leq l/2M \leq 1$), apart from mass (M) and rotation parameter (a). A rotating Simpson-Visser metric correspond to (i) a Schwarzschild metric for $l/2M = a/2M = 0$ and $M \neq 0$, (ii) a Kerr metric for $l/2M = 0$, $|a/2M| < 0.5$ and $M \neq 0$ (iii) a rotating regular black hole metric for $|a/2M| < 0.5$, $M \neq 0$ and $l/2M$ in the range $0 < l/2M < 0.5+\sqrt{(0.5)^2 - (a/2M)^2}$, and (iv) a traversable wormhole for a $|a/2M| > 0.5$ and $l/2M \neq 0$. We find a decrease in the deflection angle α_D and also in the ratio of the flux of the first image and all other images r_{mag}. On the other hand, angular position θ_1 increases more slowly and photon sphere radius x_m decreases more quickly, but angular separation s increases more rapidly, and their behaviour is similar to that of the Kerr black hole. The formalism is applied to discuss the astrophysical consequences in the supermassive black holes NGC 4649, NGC 1332, Sgr A* and M87* and find that the rotating Simpson-Visser black holes can be quantitatively distinguished from the Kerr black hole via gravitational lensing effects. We find that the deviation of the lensing observables $\Delta\theta_1$ and Δs of rotating Simpson Visser black holes from Kerr black hole for $0 < l/2M < 0.6$ ($a/2M = 0.45$), for supermassive black holes Sgr A* and M87, respectively, are in the range $0.0422 - 0.11658$ μas and $0.031709 - 0.08758$ μas while $|\Delta r_{mag}|$ is in the range $0.2037 - 0.95668$. It is difficult to distinguish the two black holes because the departure are in $\mathcal{O}(\mu\text{as})$, which are unlikely to get resolved by the current EHT observations, and one has to wait for future observations by ngEHT can pin down the exact constraint. We also derive a two-dimensional lens equation and formula for deflection angle in the strong field limit by focusing on trajectories close to the equatorial plane. This work has been done in collaboration Shafqat Ul Islam,and Jitendra Kumar

Tuhin Ghosh

Statistical isotropy of the CMB E-mode polarization

In this work, we test the statistical isotropy (SI) of the CMB E-mode polarization using two statistics, namely, the α estimator that is derived from the contour Minkowski tensor and the directional statistic ($\mathcal{D}$ statistic). The α estimator provides information about the alignment of structures and can be used to infer statistical properties such as Gaussianity and SI of random fields. The $\mathcal{D}$ statistic is based on detecting preferred directionality shown by vectors defined by the random field. We use the publicly available Planck 2018 data release component-separated SMICA CMB Stokes Q and U maps. To probe the SI at large scales and reduce the noise contribution present in the Planck data, we smooth the CMB Stokes Q and U maps to 1° FWHM beam resolution and transform it to pseudo-scalar E and B-mode maps. We consider the CMB E-mode map for the test of statistical isotropy along with the Planck collaboration recommended polarization mask retaining only 78% of the high latitude sky. We compute α and $\mathcal{D}$ statistic for the 1° smoothed CMB E-mode map, and compare it with the values calculated using FFP10 SMICA simulations. In FFP10 SMICA simulations, the CMB sky is statistically isotropic and processed through the end-to-end pipeline as the real Planck data. We find good agreement between the Planck data and the SMICA simulations for both α estimator and $\mathcal{D}$ statistic. Based on the two estimators, we can conclude that the CMB E-mode polarization is consistent with the SI assumption at large angular scales (1° or higher).

This work has been done in collaboration with Joby P. Kochappan, Aparajita Sen,Pravabati Chingangbam, and Soumen Basak

Nature of non-Gaussianity and statistical isotropy of the 408 MHz Haslam map

Some component separation methods separate the CMB from other Galactic and extragalactic foregrounds on a harmonic basis using the auto- and cross-frequency power spectra. In these methods, the foregrounds are assumed to be Gaussian while propagating the errorbars in the recovered CMB power spectrum. In this work, we test the assumption of Gaussianity and statistical isotropy of the major foreground components for CMB study, namely the Galactic synchrotron emission traced by 408 MHz Haslam map. We apply the scalar Minkowski functionals and their tensorial generalization known as Minkowski tensors. We perform the analysis as a function of sky regions and angular scales. We find that the overall level of the non-Gaussian deviations does decrease as more high emission regions are masked and as we go down to smaller scales, in agreement with the results obtained in earlier works. The non-Gaussian deviations remain of the order of 3.3σ at the smallest angular scales relevant for the Haslam map in the low emission regions. We have shown analytically that these deviations of the Minkowski functionals can be well explained by the perturbative expansion up to second-order (up to kurtosis terms), with first-order terms being sub-dominant. We also report that the Haslam map becomes increasingly more statistically isotropic at smaller scales.

This work has been done in collaboration with F. Rahman, P. Chingangbam.

Ankur Gogoi

Scattering by interstellar graphite and fayalite composite dust analogues: computer simulation and laser-based laboratory measurements

Scattering properties of irregularly shaped interstellar composite dust analogues consisting of graphite and fayalite (Fe2SiO4) were studied using discrete dipole approximation (DDA). Two dust models were developed to calculate the scattering and extinction efficiencies, single scattering albedo, asymmetry parameter, phase functions and degree of linear polarizations. Laboratory measurements were also performed at three incident wavelengths 543.5, 594.5 and 632.8 nm on chemically synthesized graphite and fayalite composite particles of sizes ranging from 0.3 to 5 lm. A comparative analysis of the theoretical and experimental results of shape- and size-averaged scattering parameters shows that changes in the percentage composition of a two-species mixture model has a pronounced effect on the light-scattering properties of dust particles. The developed computational models are successful in representing a two-species mixture of interstellar dust analogues considering diverse size, shapes and percentage composition. This technique can be applied to fit observed scattering and absorption peaks in the visible region produced by astrophysical dust, provided large number of particle species are included and the influence of more physical parameters (e.g., porosity, fluffiness, temperature, density, etc.) are considered. Further, this study is also applicable to remote sensing, atmospheric and planetary sciences. All the physical parameters employed as variables in the models influence the oscillations observed in theoretical curves and change the values of scattering parameters. This work has been done in collaboration with Manash J Boruah, and Gazi A. Ahmed.

Umananda D. Goswami

Cosmology with a new $f(R)$ gravity model in Palatini formalism

One of the most favourable extensions of General Relativity is the $f(R)$ gravity. $f(R)$ gravity in Palatini formalism can be a realistic alternative to the dark energy problem. In this work we study a recently introduced dark energy $f(R)$ gravity model along with two other models in cosmological perspectives under the Palatini formalism. First, we study the cosmic expansion history of these models with the help of the important cosmographic parameters, such as the Hubble parameter, luminosity distance, effective equation of state etc. This study shows that the new model behaves similarly with the other two models as well as with the ΛCDM model in some respects in the early or very early phases of the universe. It could predict the present accelerated expansion of the universe somewhat differently from the other models with a peculiar future history of the universe. Within a constrained range of parameters all models show a good agreement with the Union2.1 luminosity distance data. However, the new model shows a quite satisfactory agreement in the whole range of its allowed parameters than that of the other two models. We also obtain cosmological constraints on these models from the Observed Hubble Data. Further, models have been tested by using $Om(z)$ test and statefinder diagnostics. These diagnostics especially, the statefinder diagnostic shows that the evolutionary differences between these models are distinct. The evolutionary trajectories of the new model are completely different from the other two models we have considered. This work has been done in collaboration with Dhruba J. Gogoi.

Quasinormal modes of mlack holes with Non-Linear-Electrodynamic sources in Rastall Gravity

One of the notable modifications of General Relativity (GR) is the Rastall gravity. We have studied the quasinormal modes of black holes in Rastall gravity in presence of non-linear electrodynamic sources. Here the impacts of cosmological field, dust field, phantom field, quintessence field and radiation field on the quasinormal modes in presence of electrodynamic sources have been investigated. Apart from this, we have also checked the dependency of quasinormal modes with the Rastall parameter λ, black hole structural constant N_s and charge of the black hole Q. The study shows that the quasinormal modes corresponding to the black hole with non-linear electrodynamic sources show significant deviations from a general charged black hole in Rastall gravity under certain conditions. Further, the behaviour of black holes and hence the quasinormal modes depend on the type of surrounding field considered. This work has been done in collaboration with Dhruba J. Gogoi. .

Shivappa B. Gudennavar

Spectral properties of soft X-ray transient MAXI J0637−430 using AstroSat

Soft X-ray transients are systems that are detected when they go into an outburst, wherein their X-ray luminosity increases several orders of magnitude. These outbursts are markers of the poorly understood change in the spectral state of these systems from low/hard state to high/soft state. We report the spectral properties of one such soft X-ray transient: MAXI J0637−430, with data from the *SXT* and *LAXPC* instruments on-board *AstroSat* mission. The source was observed for a total of $\sim$ 60 ks over two observations on 8^{th} and 21^{st} November, 2019 soon after its discovery. Flux resolved spectral analysis of the source indicates the presence of a multi-colour blackbody component arising from the accretion disk and a thermal Comptonization component. The stable low temperature ($\sim 0.55\ keV$) of the blackbody component, points to a cool accretion disk with an inner disk radius of the order of a few hundred km. In addition, we report the presence of a relativistically broadened Gaussian line at 6.4 keV. The disk dominated flux and photon power law index of $\gtrsim 2$ and a constant inner disk radius indicate the source to be in the soft state. From the study we conclude that MAXI J0637−430 is a strong black hole X-ray binary candidate. This work has been done in collaboration with Neal T. Thomas, Ranjeev Misra, and S.G. Bubbly

Sarbari Guha

Propagation of axial and polar gravitational waves in Kantowski-Sachs universe

In this paper, we apply the Regge-Wheeler formalism in our study of axial and polar gravitational waves in Kantowski-Sachs universe. The background field equations and the linearised perturbation equations for axial and polar modes are derived in presence of matter. To find the analytical solutions, we analyse the propagation of waves in vacuum spacetime. The background field equations in absence of matter are first solved by assuming that the expansion scalar Θ to be proportional to the shear scalar σ (so that the metric coefficients are given by the relation $a = b^n$, where n is an arbitrary constant). Using the method of separation of variables, the axial perturbation parameter $h_0(t,r)$ is obtained from its wave equation. The other perturbation $h_1(t,r)$ is then determined from $h_0(t,r)$. The anisotropy of the background spacetime is responsible for the damping of the axial waves. The polar perturbation equations are much more involved compared to their FLRW counterparts, as well as to the axial perturbations in Kantowski-Sachs background, and contain complicated couplings among the perturbation variables. In both the axial and polar cases, the radial and temporal solutions for the perturbations separate out as product. The temporal part of the polar perturbation solutions are plotted against time to obtain an order of magnitude estimate of the frequency of the propagating GWs, which is found to lie in the probable range of 1000-2000 Hz. Using standard observational data for the GW strain we have placed constraints on the parameters appearing in the polar perturbation solutions. The perturbation equations in presence of matter show that the axial waves can cause perturbations only in the azimuthal velocity of the fluid without deforming the matter field. But the polar waves must perturb the energy density, the pressure and also the non-azimuthal components of the fluid velocity. The propagation of axial and polar gravitational waves in Kantowski-Sachs and Bianchi I spacetimes is found to be more or less similar in nature. This study has been done in collaboration with Sucheta Datta.

Dynamical conditions and causal transport of dissipative spherical collapse in $f(R,T)$ gravity

In this paper, we have investigated the non-adiabatic spherical gravitational collapse in the framework of the $f(R,T)$ theory of gravity with a locally anisotropic fluid that undergoes dissipation in the form of heat flux, free-streaming radiation, and shearing viscosity. The dynamical equations are analyzed in detail, both in the Newtonian and post-Newtonian regimes. Finally we couple the dynamical equations to the full causal transport equation in the context of Israel-Stewart theory of dissipative systems. This yields us a better understanding of the collapse dynamics and may be connected to various astrophysical consequences. This study has been done in collaboration with Uttaran Ghosh.

Priya Hasan

The galaxy population of the core of Coma cluster

In this paper we present the structural properties and morphology of galaxies in the central region of the Coma Cluster brighter than 19.5^m in the $F814W$ band. from the HST/ACS Coma Cluster Treasury Survey. Using mainly spectroscopic redshifts, we find 132 members from our sample of 219 galaxies. In our sample of 132 members, we find 51 non-dwarfs and 81 dwarfs and amongst our 32 non-members, we find 4 dwarfs and 28 non dwarfs. We do not have redshifts for the remaining 55 galaxies. We present bulge-disc decomposition of the sample using GALFIT and obtain parameters for our sample. Using visual inspection of residuals, we do a a morphological classification of the galaxies. We studied the relation of morphological types with Bulge to Total Light Ratio (B/T), color magnitude relation (CMR), Sérsic index (n), Kormendy relation and cross-correlations between these parameters for the bulges and galaxies.

This work helps us understand important relations between various parameters like B/T, color and n as well as insights into the merger history of these galaxies in terms of their positions in the Kormendy Diagram and their Sérsic indices. Using statistical methods, we find that the there are significantly more E/SO, SOs galaxies in the member population compared to non-members. This study has been done in collaboration with P. Nagamani, and S. N.Hasan

Membership of stars in open clusters using Random Forest with Gaia Data

Membership of stars in open clusters is one of the most crucial parameters in studies of star clusters. Gaia opened a new window in the estimation of membership because of its unprecedented 6-D data. In the present study, we used published membership data of nine open star clusters as a training set to find new members from Gaia DR2 data using a supervised random forest model with a precision of around 90%. The number of new members found is often double the published number. Membership probability of a larger sample of stars in clusters is a major benefit in determination of cluster parameters like distance, extinction and mass functions. We also found members in the outer regions of the cluster and found sub-structures in the clusters studied. The color magnitude diagrams are more populated and enriched by the addition of new members making their study more promising. This study has been done in collaboration with Md Mahmudunnobe, Mudasir Raja, and S N Hasan.

Golam Mortuza Hossain

Higher mass limits of neutron stars from the equation of states in curved spacetime

In order to solve the Tolman-Oppenheimer-Volkoff equations for neutron stars, one routinely uses the equation of states which are computed in the Minkowski spacetime. Using a first-principle approach, it is shown that the equation of states which are computed within the curved spacetime of the neutron stars include the effect of gravitational time dilation. It arises due to the radially varying interior metric over the length scale of the star and consequently it leads to a much higher mass limit. As an example, for a given set of parameters in a $\sigma-\omega$ model of nuclear matter, the maximum mass limit is shown to increase from $1.61M_\odot$ to $2.24M_\odot$ due to the inclusion of gravitational time dilation. This work has been done in collaboration with S. Mandal.

The methods of thermal field theory for degenerate quantum plasmas in astrophysical compact objects

In the study of degenerate plasmas contained within compact astrophysical objects, both special relativity and general relativity play important roles. After reviewing the existing treatment in the literature, here we employ the methods of relativistic thermal quantum field theory to compute the equation of states of degenerate matter for compact astrophysical objects such as the white dwarfs and the neutron stars. In particular, we compute the equation of states that include leading order corrections due to the finite temperature, the fine-structure constant as well as the effect of gravitational time dilation. We show that the fine-structure constant correction remains well-defined even in the non-relativistic regime in contrast to the existing treatment in the literature. This work has been done in collaboration with S. Mandal.

Deepak Jain

A non-parametric test of variability of Type Ia supernovae luminosity and CDDR

The first observational evidence for cosmic acceleration appeared from Type Ia supernovae (SNe Type Ia) Hubble diagram from two different groups. However, the empirical treatment of SNe Type Ia and their ability to show cosmic acceleration have been the subject of some debate in the literature. In this work we probe the assumption of redshift-independent absolute magnitude (M_B) of SNe along with its correlation with spatial curvature (Ω_{ko}) and cosmic distance duality relation (CDDR) parameter ($\eta(z)$). This work is divided into two parts. Firstly, we check the validity of CDDR which relates the luminosity distance (d_L) and angular diameter distance (d_A) via redshift. We use the Pantheon SNe Ia dataset combined with the H(z) measurements derived from the cosmic chronometers. Further, four different redshift-dependent parametrizations of the distance duality parameter ($\eta(z)$) are used. The CDDR is fairly consistent for almost every parametrization within a 2σ confidence level in both flat and a non-flat universe. In the second part, we assume the validity of CDDR and emphasize on the variability of M_B and its correlation with (Ω_{ko}). We choose four different redshift-dependent parametrizations of M_B. The results indicate no evolution of M_B within 2σ confidence level. For all parametrizations, the best fit value of Ω_{ko} indicates a flat universe at 2σ confidence level. However a mild inclination towards a non flat universe is also observed. We have also examined the dependence of the results on the choice of different priors for H_0. This work has been done in collaboration with D. Kumar, A. Rana, Deepak Jain, S. Mahajan, A. Mukherjee, and R. F. L. Holanda.

Strong lensing systems and galaxy cluster observations as probe to the cosmic distance duality relation

In this paper, we use large scale structure observations to test the redshift dependence of cosmic distance duality relation (CDDR), $D_L(1+z)^{-2}/D_A = \eta(z)$, with D_L and D_A, being the luminosity and angular diameter distances, respectively. In order to perform the test, the following data set are considered: strong lensing systems and galaxy cluster measurements (gas mass fractions). No specific cosmological model is adopted, only a flat universe is assumed. By considering two $\eta(z)$ parametrizations, It is observed that the CDDR remain redshift independent within 1.5σ which is in full agreement with other recent tests involving cosmological data. It is worth to comment that our results are independent of the baryon budget of galaxy clusters. This work has been done in collaboration with R. F. L. Holanda, F. S. Lima, and A. Rana.

Jessy Jose

Subaru Hyper Suprime-Cam Survey of Cygnus OB2 Complex - I. Introduction, photometry, and source catalogue

Low mass star formation inside massive clusters is crucial to understand the effect of cluster environment on processes like circumstellar disk evolution, planet and brown dwarf formation. The young massive association of Cygnus OB2, with a strong feedback from massive stars, is an ideal target to study the effect of extreme environmental conditions on its extensive low-mass population. We aim to perform deep multi-wavelength studies to understand the role of stellar feedback on the IMF, brown dwarf fraction and circumstellar disk properties in the region. We introduce here, the deepest and widest optical photometry of 1.5° diameter region centred at Cygnus OB2 in r_2, i_2, z and Y-filters using Subaru Hyper Suprime-Cam (HSC). This work presents the data reduction, source catalog generation, data quality checks and preliminary results about the pre-main sequence sources. We obtain 713,529 sources in total, with detection down to $\sim$ 28 mag, 27 mag, 25.5 mag and 24.5 mag in r_2, i_2, z and Y-band respectively, which is $\sim$ 3 - 5 mag deeper than the existing Pan-STARRS and GTC/OSIRIS photometry. We confirm the presence of a distinct pre-main sequence branch by statistical field subtraction of the central $18'$ region. We find the median age of the region as $\sim 5 \pm 2$ Myrs with an average disk fraction of $\sim$ 9%. At this age, combined with $A_V \sim$ 6 - 8 mag, we detect sources down to a mass range $\sim$ 0.01 - 0.17 $M_\odot$. The deep HSC catalog will serve as the groundwork for further studies on this prominent active young cluster. This work has been done in collaboration with Saumya Gupta.

A novel survey for young substellar objects with the W-band filter III: Searching for very low-mass brown dwarfs in Serpens South and Serpens Core

We present CFHT photometry and IRTF spectroscopy of low-mass candidate members of Serpens South and Serpens Core ($\sim$ 430 pc, $\sim$ 0.5 Myr), identified using a novel combination of photometric filters, known as the W-band method. We report SC182952+011618, SS182959-020335, and SS183032-021028 as young, low-mass Serpens candidate members, with spectral types in the range M7-M8, M5-L0, and M5-M6.5, respectively. Best-fitting effective temperatures and luminosities imply masses of $\leq 0.12 M_\odot$ for all three candidate cluster members. We also present Hubble

Space Telescope imaging data (F127M, F139M, and F850LP) for six targets in Serpens South. We report the discovery of the binary system SS183044-020918AB. The binary components are separated by ~ 45 AU, with spectral types of M7-M8 and M8-M9, and masses of 0.08-0.1 and 0.05-0.07 M$\odot$. We discuss the effects of high dust attenuation on the reliability of our analysis, as well as the presence of reddened background stars in our photometric sample. This work has been done in collaboration with Sophie Dubber, Beth Biller, Katelyn Allers, et al.

Minu Joy

Ringing Non-Gaussianity from ination with a step in the second derivative of the potential

Inationary model driven by a scalar eld whose potential has a step in the second derivative with respect to the eld is considered. For the best t potential parameter values, the 3-point function and the nonGaussianity associated with the featured model is calculated. We study the shape and scale dependence of the 3-point function. The distinctive feature of this model is its characteristic ringing behaviour of fNL. We can see that the oscillations in fNL in this model last for a much longer range of k values, as compared to the previously studied models. In that sense, this model is potentially distinguishable from models with other features in the potential. This work has been done in collaboration with Rakhi R.

Mehedi Kalam

Properties of rotating neutron stars in light of binary compact object mergers

The properties of rotating neutron stars are investigated using eight equations of state (EOSs). We also study the relations between various observables corresponding to different angular velocities for all those EOSs. All of these EoSs lead to non-rotating compact stars with maximum masses between 1.8 to 2.25 $M_{\odot}$. We calculate the moment of inertia and studied its variation with mass and the relation between central energy density and angular momentum. We compare our results with the observational findings from the most massive pulsar PSR J0740+6620 and the heaviest secondary component in the black holeneutron star merger GW190814. It is noted that the secondary compact object of GW190814 having mass $\sim 2.6M_{\odot}$ might be explained as a rapidly rotating neutron star (NS) with frequency larger than 1000 Hz. This work has been done in collaboration with Bidisha Ghosh.

Traversable wormhole on the brane with non-exotic matter: a broader view

In this article, the possibility of construction of a traversable wormhole on the Randall-Sundrum braneworld with non-exotic matter employing the Kuchowicz potential has been studied. We have obtained the solution for the shape function of the wormhole and studied its properties along with validity of Null Energy Condition (NEC). The junction conditions at the surface of the wormhole are used to evaluate the model parameters. We also evaluate the surface density and surface pressure for the wormhole. We study the geometrical nature of the wormhole and consider the radial and tangential tidal constraints on a traveler trying to traverse the wormhole. Besides, a linearized stability analysis is performed to obtain the region of stability for the wormhole. Our analysis, besides giving an estimate for the bulk equation of state (EoS) parameter, imposes restrictions on the brane tension, which is a very essential parameter in braneworld physics, and very interestingly the restrictions imposed by our physically plausible and traversable wormhole model are in conformity with those imposed by other braneworld geometries which are not associated with a wormhole solution. Besides, it is important to study such constraints imposed by geometrical objects such as wormholes on any gravity theory operating at high-energy scales like braneworld, as wormholes are believed to have been formed from massive compact objects of high energy densities. Also, we go on to justify that the possible detection of a wormhole may well indicate that we live on a three-brane universe. This work has been done in collaboration with Rikpratik Sengupta1, Shounak Ghosh, and Saibal Ray.

Nishikanta Khandai

Redshift space three-point correlation function of IGM at $z < 0.48$

The Ly α forest decomposed into Voigt profile components allow us to study clustering properties of the intergalactic me dium and its dependence on various physical quantities. Here, we report the first detections of probability excess of low-z (i.e $z < 0.48$) Ly α absorber triplets over a scal e of $r_{\parallel} \leq 8$ pMpc with a maximum amplitude of $8.76^{+1.96}_{-1.65}$ at a longitudinal separation of 1-2 pMpc We measure non-zero three-point correlation ($\zeta = 4.76^{+1.98}_{-1.67}$) only at this scale with reduced three-point correlation value of Q $= 0.95^{+0.39}_{-0.38}$. The measured ζ shows an increasing trend with increasing H I column density (N_{HI}) while Q does not show any (N_{HI}) dependence. driven by the signal-to-noise ratio of the spectra used. About 88% of the triplets contributing to ζ (at $z \leq 0.2$) have nearby galaxies (whose distribution is known to be complete for 0.1 L_* at $z < 0.1$ and for L_* at $z \sim 0.25$ and within 20' to the quasar sightlines) within a velocity separation of 500 kms^{-1} and a median impact parameter of 405 pkpc. The measured impact parameters are c onsistent with appreciable number of triplets at $z \leq 0.2$ not originating from individual galaxies but tracing the un derlying galaxy distribution. Frequency of occurrence of high-b absorbers in triplets (∼85%) is a factor ∼ 3 higher than that found among the full sample (∼32%) . Using four different cosmological simulations, we quantify the effect of peculiar velocities, feedback effects and show that m ost of the observed trends are broadly reproduced. However, ζ at small scales ($r_{\|} < 1$ pMpc) and b-depend ence of ζ in simulations are found inconsistent with the observations. This could either be related to the fact tha t none of these simulations reproduce the observed b-distribution and N_{HI} distribution for N_{HI} $> 10^{14}$ cm^{-2} self-consistently or to the widespread of signal-to-noise ratio in the observed data. This work has been done in collaboration with S. Maitra, R. Srianand, and P. Gaikwad.

Ram Kishor

First order stability test of equilibrium points in the planar elliptic restricted four body problem with radiating primaries

This paper presents a rigorous analysis of existence of equilibrium points and corresponding their first order stability test in the planar elliptic restricted four body problem under the influence of radiation pressure forces due to radiating primaries. In the presence of radiation pressure of the radiating primaries, a considerable variations in position co-ordinates of the equilibrium points and in their stability ranges have seen. Also, the existence of equilibrium points with respect to the values of eccentricity e and true anomaly f in their respective ranges have analysed and it is found that number of equilibrium points reduces with the increasing value of eccentricity within the range $0 < e < 1$, whereas a random variation is seen in case of true anomaly $f \in [0, 2\pi]$. The results of this study will be helpful to study more generalised problems with different kind of perturbations such as oblateness, solar wind drag, PR drag, Stokes drag etc. This work has been done in collaboration with Poonam Meena.

Motion about equilibrium points in the Jupiter-Europa system with oblateness

The study of motion of a test mass in the vicinity of an equilibrium point under the frame of restricted three body problem (RTBP) plays an important role in the trajectory design for different space missions. In this paper, motion of an infinitesimal mass has been described under the frame of Jupiter-Europa system with oblateness. At first, we have determined equilibrium points and then performed linear stability tests under the influence of oblateness of both the primaries. We found that due to oblateness, a considerable deviation in the existing results has occurred. Next, we have computed tadpole and horseshoe orbits in the neighbourhood of triangular equilibrium points and then the oblateness effect is recorded on these orbits. Finally, the evolution of orbits of infinitesimal mass about triangular equilibrium points have been estimated by using Poincaré surface of section technique and it is noticed that in presence of oblateness, quasi-periodic orbit dominates over the chaotic zones. These results will help in further study of more generalised models with perturbations. This work has been done in collaboration with Saleem Yousuf1, and Manoj Kumar.

Nagendra Kumar

Kelvin-Helmholtz instability in flowing dusty and partially ionized plasmas

The Kelvin-Helmholtz instability is a macroscopic magnetohydrodynamic instability which arises at the interface between two fluids in relative motion. It has been extensively investigated to understand various physical phenomena occurring in the environment of space and interplanetary medium. We investigate the effect of different flow velocities on KelvinHelmholtz instability arising in partially ionized dusty plasmas. The basic equations governing the motion of partially ionized dusty plasma have been linearized to obtain the dispersion relation by applying the boundary conditions. Dispersion relation is solved numerically to discuss the growth rate of unstable mode. It is found that unstable mode doesnt appear in the absence of relative motion but our results show a stabilizing effect for lower values of relative motion. It is also found that growth time scale of unstable modes increases as the relative motion increases and the flow in region without dust particles has a dominant effect on growth rate of unstable mode. This work has been done in collaboration with Harendra Singhal, Meenakshi Yadav and Anil Kumar.

R. K. Sunil Kumar

Data Preprocessing Techniques for Handling Time Series data for Environmental Science Studies

The present article discusses various preprocessing techniques suitable for dealing with time series data for environmental science-related studies. The errors or noises due to electronic sensor fault, fault in the communication channel, etc., are considered here. Such errors or glitches that occur during the data acquisition or transmission phases need to be eliminated before it fed to the forecasting or classification systems. Computationally simple and efficient techniques are discussed here so that they can even be adopted for a hard real-time system environment. While adopting these techniques, we may also end up with some of the real genuine values, which may consider as an outlier. A special indicator function, the moving Inter Quartile Range (MIQR) algorithm, is proposed to overcome such special cases. This work has been done in collaboration with Ebin Antony, N. S. Sreekanth, and Nishanth T.

Reconstruction of Phase Space and Eigenvalue Decomposition from a Biological Time Series: A Malayalam Speech Signal Case Study

Our objective is to describe the speech production system from a non-linear physiological system perspective and reconstruct the attractor from the experimental speech data. Mutual information method is utilized to find out the time delay for embedding. The False Nearest Neighbour (FNN) method and Principal Component Analysis (PCA) method are used for optimizing the embedding dimension of time series. The time series obtained from the typical non-linear systems, Lorenz system and Rssler system, is used to standardize the methods and the Malayalam speech vowel time series of both genders of different age groups, sampled at three sampling frequencies (16kHz, 32kHz, 44.1kHz), are taken for analysis. It was observed that time delay varies from sample to sample and, it ought to be better to figure out the time delay with the embedding dimension analysis. The embedding dimension is shown to be independent of gender, age and sampling frequency and can be projected as five. Hence a five-dimensional hyperspace will probably be adequate for reconstructing attractor of speech time series. This work has been done in collaboration with K. M. Muraleedharan, K. T. Bibish Kumar, and Sunil John.

Suresh Kumar

Remedy of some cosmological tensions via effective phantom-like behavior of interacting vacuum energy

Since physics of the dark sector components of the Universe is not yet well-understood, the phenomenological studies of non-minimal interaction in the dark sector could possibly pave the way to theoretical and experimental progress in this direction. Therefore, in this work, we intend to explore some features and consequences of a phenomenological interaction in the dark sector. We use the Planck 2018, BAO, JLA, KiDS and HST data to investigate two extensions of the base ΛCDM model, viz., (i) we allow the interaction among vacuum energy and dark matter, namely the IΛCDM model, wherein the interaction strength is proportional to the vacuum energy density and expansion rate of the Universe, and (ii) the IΛCDM scenario with free effective neutrino mass and number, namely the νIΛCDM model. We also present comparative analyses of the interaction models with the companion models, namely, ΛCDM, νΛCDM, wCDM and νwCDM. In both the interaction models, we find non-zero coupling in the dark sector up to 99% CL with energy transfer from dark matter to vacuum energy, and observe a phantom-like behavior of the effective dark energy without actual "phantom crossing". The well-known tensions on the cosmological parameters H_0 and σ_8, prevailing within the ΛCDM cosmology, disappear in these models wherein the νIΛCDM model shows consistency with the standard effective neutrino mass and number. Both the interaction models find a better fit to the combined data compared to the companion models under consideration.

Relaxing cosmological tensions with a sign switching cosmological constant

Inspired by the recent conjecture originated from graduated dark energy that the Universe has recently transitioned from anti-de Sitter vacua to de Sitter vacua, we extend the standard ΛCDM model by a cosmological constant (Λ_s) that switches sign at a certain redshift

$z_\dagger$, and we call this model Λ_sCDM. We discuss the construction and theoretical features of this model in detail and find out that, when the consistency of the Λ_sCDM model with the cosmic microwave background (CMB) data is ensured, (i) $z_\dagger \gtrsim 1.1$ is implied by the condition that the Universe monotonically expands, (ii) H_0 and M_B (type Ia supernovae absolute magnitude) values are inversely correlated with $z_\dagger$ and reach $H_0 \approx 74.5\ \mathrm{km\,s^{-1}\,Mpc^{-1}}$ and $M_B \approx -19.2\,\mathrm{mag}$ for $z_\dagger = 1.5$, in agreement with the SH0ES measurements, and (iii) $H(z)$ presents an excellent fit to the Ly-α measurements provided that $z_\dagger \lesssim 2.34$. We further investigate the model constraints by using the full *Planck* CMB data set, with and without baryon acoustic oscillation (BAO) data. We find that the CMB data alone does not constrain $z_\dagger$, but the CMB+BAO data set favors the sign switch of Λ_s providing the constraint: $z_\dagger = 2.44 \pm 0.29$ (68% C.L.). Our analysis reveals that the lower and upper limits of $z_\dagger$ are controlled by the Galaxy and Ly-α BAO measurements, respectively, and the larger $z_\dagger$ values imposed by the Galaxy BAO data prevent the model from achieving the highest local H_0 measurements. In general, the Λ_sCDM model (i) relaxes the H_0 tension while being fully consistent with the tip of the red giant branch measurements, (ii) relaxes the M_B tension, (iii) removes the discrepancy with the Ly-α measurements, (iv) relaxes the S_8 tension, and (v) finds a better agreement with the big bang nucleosynthesis constraints on the physical baryon density. We find no strong statistical evidence to discriminate between the Λ_sCDM and ΛCDM models. However, interesting and promising features of the Λ_sCDM model, which we describe in our study, provide an advantage over ΛCDM. This work has been done in collaboration with Ozgur Akarsu, Suresh Kumar, Emre Ozulker, and J. Alberto Vazquez.

Vinjanampaty Madhurima

Hydrogen bonding in 1-Propanol-Ethanol binary mixture: rxperimental and modeling approaches

Hydrogen bonds between the constituent molecules determine the physical properties of binary liquids. In this work, we explore the nature of hydrogen bonding in ethanol-propanol system through experimental and computational techniques. The refractive index, dielectric spectroscopy and infrared spectroscopy along with molecular dynamic simulations of 1-propanol-ethanol binary system over the entire concentration range are reported here. The excess static permittivity and excess relaxation time shows the evidence of hydrogen bonded multimer structures. The deconvoluted OH peaks from IR spectra indicate the presence of trimers, tetramers and pentamers. The linear decrease in refractive index indicates the absence of caged structures. Molecular Dynamics simulations confirm the presence of the multimers and the absence of caged structures. Radial distribution function shows the binary mixtures exhibit no structural change throughout the concentration range. We also examine the H-bonding networks present in these systems via graph theoretic analysis.. This work has been done in collaboration with Swathi P V, Abdulkareem U, and Thejus R Kartha.

Hydrogen bonding in 1-Hexanol-Acetone binary mixture: molecular dynamics study

Our previous studies on various hydrogen-bonded binary systems have shown anomalous physico-chemical properties at lower (10-30 %) volume concentrations of either one or both of the components[1]. In order to have a better understanding of this phenomenon, a systematic molecular dynamics study of binary mixtures of acetone with 8 primary alcohols (R-OH, with R = 1 to 8) was undertaken. The radial distribution function results indicate that the hydrogen bond distribution among alcohols in R=(1, 2) increases as the concentration of acetone increases, indicating the hydrogen bond networks are not disrupted by acetone, unlike that of higher alcohols. It is also seen, from the hydrogen bond statistics, that the number of acetone-alcohol hydrogen bonds are predominant for R= (3, 4, 6) and the hydrogen bonds between alcohols a for the rest, suggesting R= (3, 4, 6) are attractive to acetone compared to other alcohols. The hydrogen bond networks are visualized using the graph-theoretical approach to get a clearer picture of their hydrogen-bonding network. With an increase in acetone concentration, the average number of degrees of association decreases for all systems, showing an overall decrease in hydrogen bond multimers structures. This work has been done in collaboration with Abdulkareem U, and Thejus R Kartha.

Bibhas R. Majhi

Kinematics and dynamics of null hypersurfaces in the Einstein-Cartan spacetime and related thermodynamic interpretation

A general geometric construction of a generic null hypersurface in presence of torsion in the spacetime (Riemann-Cartan background), generated by a null vector l^a, is being developed here. We then explicitly define and structure various corresponding kinematical quantities. The dynamics of the null surface, particularly given by $\hat{G}_{ab}k^a l^b$, is also discussed. The later one is constructed under the *geodesic constraint* condition. This yields a relation among the rate of change of expansion scalar corresponding to auxiliary null vector k^a and various kinematical entities on the null surface. Using this relation we show that the Einstein-Cartan-Kibble-Sciama equation (which provides the dynamics of the metric and the torsion tensor) on this null hypersurface acquires a thermodynamic interpretation. The thermodynamic entities like temperature, entropy density, energy and pressure are properly identified. In the whole analysis we adopt the geometrical field interpretation of torsion and all discussions are done in a covariant manner. This work has been done in collaboration with Sumit Dey.

Thermal nature of a generic null surface

Dynamical properties of a generic null surface are known to have a thermodynamic interpretation. Such an interpretation is completely based on an analogy between the usual law of thermodynamics and structure of gravitational field equation on the surface. Here we materialise this analogy and show that assigning a temperature on the null surface for a local observer is indeed physically relevant. We find that for a local frame, chosen as outgoing massless chargeless particle (or field mode), perceives a "*local unstable Hamiltonian*" very near to the surface. Due to this it has finite quantum probability to escape through acausal null path which is given by Maxwell-Boltzmann like distribution, thereby providing a temperature on the surface. This work has been done in collaboration with Surojit Dalui, and T. Padmanabhan.

Manzoor A. Malik

Airglow-imager based observation of possible influences of subtropical mesospheric gravity waves on F-region ionosphere over Jammu & Kashmir, India

As a joint research collaboration between the National Atmospheric Research Laboratory (NARL), and the University of Kashmir (KU), NARL installed an all-sky airglow CCD imager (with centre wavelengths of 630 nm, 557.7 nm [2 nm band widths] and 840 nm [150 nm wide band with blocking notch at 866 nm to avoid the contamination of molecular oxygen emissions]) in the University campus in Srinagar (75E, 34N, geographic), Jammu and Kashmir, India (western Himalayan region). To understand the upper atmospheric dynamics and ionospheric electrodynamics and their associated physical coupling mechanisms, the imager observes airglow emissions of OH molecules (85 km height; 840 nm) and atomic oxygen occurring at the heights of 97 km (557.7 nm) and 250 km (630 nm). Airglow observations in Kashmir commenced in the night of August 11, 2017 and the present work reports on the characteristics of first-time observation of Medium Scale Travelling Ionospheric Disturbances (MSTIDs with horizontal wavelengths of 100300 km) over Kashmir region during 20:3022:30 IST (Indian standard time) on August 15, 2017 (India independence day). Initially, the phase front of MSTIDs was aligned along the north-west and south-east direction and moved at 57 m/s towards the south-west direction and finally the westward direction by aligning along the meridian before they disappeared. Along with SAMI-3 ionospheric model simulations, simultaneous multiwavelength airglow observations indicate that secondary gravity waves generated due to dissipation of upward propagating mesospheric gravity waves in the heights of 8595 km would have contributed to the generation of MSTIDs in the F region ionospheric plasma through electrodynamical coupling between the E and F region (Perkins instability) ionosphere. This work has been done in collaboration with T. K. Ramkumar, Bilal A. Ganaie, and Aashiq H. Bhat.

Simultaneous detection of medium-scale traveling ionospheric disturbances and ionospheric plasma irregularities over Srinagar, J& K, India

We report some ionospheric phenomena that occurred on September 23, 2019 observed by an airglow imager installed at University of Kashmir, Srinagar, India (34.08N, 74.79E, and 25.91N magnetic latitude). The various phenomena observed on this night are as follows: (1) The wave-like structures near the dusk time having phase fronts aligned along Northwest to Southeast direction and moving southwestward, classified as nighttime medium-scale traveling ionospheric disturbance. (2) Simultaneous observation of northwestward-moving nighttime medium-scale traveling ionospheric disturbances and eastward-drifting plasma irregularity and (3) The westward reversal of field-aligned plasma irregularity and K-shaped depletion structure formation post-midnight. We analyze their characteristics and evolution processes in detail. The plasma irregularity seems to be the signature of locally generated plasma irregularities at low-mid-latitude transition region as the radar observations from a geomagnetic low-latitude station (Gadanki, India; 13.5N, 79.2E, Magnetic latitude 6.5N) do not show any signatures of equatorial plasma bubbles during this night. It is interesting to note that the westward reversal of plasma irregularity occurred even when the geomagnetic conditions were at quiet levels (Kp 0 to 1+). Though the observed nighttime MSTIDs and plasma irregularity bands are two different events, yet the structures appear to interact with each other, the apparent mechanism leading to the quiet time westward reversal of plasma irregularity structures at midnight and the development of complex K-shaped depletion structure. Interaction between these phenomena and their observed characteristic features is also discussed.

This work has been done in collaboration with Aashiq Hussain Bhat, Bilal Ahmad Ganaiel,and T. K. Ramkumar.

Irom A. Meitei

Quantum gravity corrections to tunneling of spin-1/2 fermions from Kerr-Newman Black Hole

In this paper, we solve the Dirac equation in curved space-time, modified by the generalized uncertainty principle, in the presence of an electromagnetic field. Using this, we study the tunneling of 1/2 spin fermions from Kerr-Newman black hole. Corrections to the Hawking temperature and entropy of the black hole due to quantum gravity effects are also discussed. This work has been done in collaboration with A. K. Singh, T. I. Singh, and K. Y. Singh.

Quantum gravity effects on tunneling of fermions across the event horizon of rotating BTZ black hole

In this paper, the tunneling of fermions across the event horizon of rotating BTZ black hole is investigated by using Dirac equation in the presence of quantum gravity effects, WKB approximation and Feynman prescription. The tunneling probability and the modified Hawking temperature near the event horizon of rotating BTZ black hole are obtained. The quantum gravity effects reduce the rise of Hawking temperature of rotating BTZ black hole. The correction to the Bekenstein-Hawking entropy and the heat capacity near the event horizon of rotating BTZ black hole are also discussed. This work has been done in collaboration with S. Gayatri Devi, and T. Ibungochouba Singh and K. Yugindro Singh..

Hameeda Mir

Gravitational partition function modified by super-light brane world perturbative modes

In this paper, we will analyze the effects of super-light brane world perturbative modes on clustering of galaxies. In present manuscript, we use the Boltzmann and Tsallis statistical approaches to study the large distance modification of gravity in the brane world. The impact of modified potential on clustering of galaxies is analyzed in both the approaches. The infinities associated with Newtonian point mass approximation of gravity models is removed using the analytical extensions. The regularized and finite partition function is obtained for the system of galaxies in the brane world model and is used to evaluate the regularized thermodynamic properties of the system in the form of equations of state. Hence, we study thermodynamic quantities and discuss about the thermodynamic stability of the model. We find that large number of galaxies may lead to the thermodynamic instability. This work has been done in collaboration with B. Pourhassan, M.C.Rocca, and Aram Bahroz Brzo.

Generalized theory of clustering of extended galaxies with core halos

We discuss the clustering of core halo-galaxies of radius predicted by gravitational lensing. We appeal to a blend of recent 1) mathematical results and 2) statistical mechanics techniques. The exact configurational integrals of extended galaxies is evaluated together with the pertinent partition functions, the corresponding thermodynamics, and the distribution function. We are motivated by data regarding observational deflections and measured Einstein radius in gravitational microlensing and macrolensing. The halo size comparable with that of the Einstein radius or the Schwarzchild one, is taken as the lower limit of the configurational integral. The work may provide new insight with regards to gravitational lensing. Giant arcs produced by gravitational lensing, as observed from clusters of galaxies, seem to require the inclusion of substantial quadruple and higher multipole moments in the cluster potential. This opens a possibility of "modified gravities" , in clustering studies that compare data associated to gravitational lensing. This study has been done in collaboration with A. Plastino, M.C.Rocca, D. J. Zamora.

Bivudutta Mishra

Rip cosmological models in extended symmetric teleparallel gravity

In this paper we have investigated some rip cosmological models in an extended symmetric teleparallel gravity theory. We consider the form $f(Q,T) = aQ^m + bT$ in the Einstein-Hilbert action and expressed the field equations and the dynamical parameters in terms of the non-metricity Q. Three rip models such as Little Rip, Big Rip and Pseudo Rip are presented. The energy conditions and the cosmographic parameters are derived and analysed for all these models. This work has been done in collaboration with Laxmipriya Pati, S.A. Kadam,and S.K. Tripathy.

Bouncing cosmology in extended gravity and its reconstruction as dark energy model

In this paper, we have presented a bouncing cosmological model of the Universe in an extended theory of gravity. The dynamical behaviour of the model obtained from the flat FLRW space-time along with the violation of null energy condition have been shown. The geometrical parameters show singularity behaviour at the bouncing epoch. The parameters involved in the scale factor play a major role in the bouncing behaviour. In addition, the coupling parameter that resulted in the minimal matter-geometry coupling in the extended gravity has significant role to avoid the singularity of equation of state parameter at the bouncing epoch. Using a linear homogeneous perturbation calculation, we show the stability of the model. This work has been done in collaboration with A.S. Agrawal, Francisco Tello-Ortiz, and S.K. Tripathy.

Sajahan Molla

Analytical model on mass limits of strange stars

In this paper, we present a new kind of stellar model using the Nariai IV metric. This model can be used to study the strange/quark stars (which is our current interest, although it can also be applicable to neutron stars). We present a massradius region where all regularity conditions, energy conditions, the TOV equation, and stability conditions are satisfied. According to our model, strange stars with masses up to $1.9165M_{\odot}(= 2.81$ km) are stable. A strange star with a mass greater than $1.9165M_{\odot}$ violates the stability conditions. This model can be very useful to predict the radius of strange stars with a mass greater than $1M_{\odot}$. This work has been done in collaboration with Masum Murshid and Mehedi Kalam

Hemwati Nandan

Optical and thermodynamic properties of a rotating dyonic black hole spacetime in $\mathcal{N} = 2, U(1)^2$ gauged supergravity

The null geodesics and the distance of closest approach for photon around a rotating dyonic black hole in $\mathcal{N} = 2, U(1)^2$ gauged supergravity is studied. The phenomenon of black hole shadows with various black hole parameters has also analyzed. Further, the investigation of various thermodynamic properties for this black hole is performed with various thermodynamic parameters at the horizon. The heat capacity to study the thermodynamic stability of this black hole spacetime is also studied. The influence for different values of the black hole parameters ν, e, ν, g and N_g on the phenomenon of black hole shadows and thermodynamic parameters is also investigated visually. This work has been done in collaboration with Prateek Sharma, Hemwati Nandan, Uma Papnoi, and Arindam Kumar Chatterjee

Stability analysis of circular orbits around a traversable wormhole with massless conformally coupled scalar field

We study the stability of circular orbits in the background of a traversable wormhole (TWH) spacetime obtained as a solution of Einsteins field equations coupled conformally to a massless scalar field. The Lyapunov stability approach is employed to determine the stability of circular orbits (timelike and null) of non-spinning test particles around a TWH spacetime. In the case of timelike geodesics, the particle is confined to move in four different types of effective potentials depending on various values of the angular momentum $\tilde{L}$ with both centrifugal and gravitational part. The effective potential for null geodesics consists of only a centrifugal part. Further, we characterize each fixed point according to its Lyapunov stability, and thus classify the circular orbits at the fixed point into stable center and unstable saddle points by depicting the corresponding phase-portraits. This work has been done in collaboration with Shobhit Giri, Lokesh Kumar Joshi , and Sunil D. Maharaj

Dibyendu Nandi

Solar evolution and extrema: current state of understanding of long-term solar variability and its planetary impacts

The activity of stars such as the Sun varies over timescales ranging from the very short to the very long—stellar and planetary evolutionary timescales. Experience from our solar system indicates that short-term, transient events such as stellar flares and coronal mass ejections create hazardous space environmental conditions that impact Earth-orbiting satellites and planetary atmospheres. Extreme events such as stellar superflares may play a role in atmospheric mass loss and create conditions unsuitable for life. Slower, long-term evolutions of the activity of Sun-like stars over millennia to billions of years result in variations in stellar wind properties, radiation flux, cosmic ray flux, and frequency of magnetic storms. This coupled evolution of star-planet systems eventually determines planetary and exoplanetary habitability. The Solar Evolution and Extrema (SEE) initiative of the Variability of the Sun and Its Terrestrial Impact (VarSITI) program of the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP) aimed to facilitate and build capacity in this interdisciplinary subject of broad interest in astronomy and astrophysics. In this review, we highlight progress in the major themes that were the focus of this interdisciplinary program, namely, reconstructing and understanding past solar activity including grand minima and maxima, facilitating physical dynamo-model-based predictions of future solar activity, understanding the evolution of solar activity over Earth's history including the faint young Sun paradox, and exploring solar-stellar connections with the goal of illuminating the extreme range of activity that our parent star—the Sun—may have displayed in the past, or may be capable of unleashing in the future. This work has been done in collaboration with Petrus C. H. Martens, Vladimir Obridko, Soumyaranjan Dash and Katya Georgieva

Modelling the imposed magnetospheres of Mars-like exoplanets: star-planet interactions and atmospheric losses

Based on 3D compressible magnetohydrodynamic simulations, we explore the interactions between the magnetized wind from a solar-like star and a Mars-like planet - with a gravitionally stratified atmosphere - that is either non-magnetized or hosts a weak intrinsic dipolar field. The primary mechanism for the induction of a magnetosphere around a non-magnetized conducting planet is the pile-up of stellar magnetic fields in the day-side region. The magnetopause stand-off distance decreases as the strength of the planetary dipole field is lowered and saturates to a minimum value for the case of a planet with no magnetic field. Global features such as bow shock, magnetosheath, magnetotail, and strong current sheets are observed in the imposed magnetosphere. We explore variations in atmospheric mass loss rates for different stellar wind strengths to understand the impact of stellar magnetic activity and plasma winds - and their evolution - on (exo)planetary habitability. In order to simulate a case analogous to the present-day Mars, a planet without atmosphere is considered. Our simulations are found to be in good agreement with observational data from Mars Global Surveyor and Mars Atmosphere and Volatile EvolutioN missions and is expected to complement observations from the Emirates (Hope) Mars Mission, China's Tianwen-1 and NASA's Mars 2020 Perseverance mission. This work has been done in collaboration with Arnab Basak.

P. R Prince

A study of the characteristic properties of SEP events observed by SOHO ERNE during solar cycle 24

Properties and association of Solar Energetic Particle (SEP) events with their solar sources during the 24th solar cycle were examined. SEPs observed by SOHO ERNE were used. SEP properties include solar release time, peak proton flux and total fluence in different energy channels. Solar release times of SEP events were found out using Velocity Dispersion Analysis (VDA). It is observed that for low Coronal Mass Ejection (CME) velocities, the difference between SEP and CME release times is larger compared to that for high velocities. For SEPs associated with C class Solar Flares (SF), the average time difference in the release times is around 78minutes, whereas in M and X class flares the time differences are 38 and 31 minutes respectively. Correlation analysis of proton peak flux with the CME speed and SF peak flux reveals that the coefficients decrease with increase in particle energy in both the cases. The correlation coefficient between total proton fluence of SEP and the peak flux of SF is moderate and decrease with increase in energy and tends to increase beyond 60MeV. The correlation between total proton fluence and CME speed is high and it increases initially and then decrease with increase in energy. The analysis of H/He ratio of SEP events shows that the average value of the ratio extends from 16 to 837. This work has been done in collaboration with M.S. Biji.

Biswajit Pandey

On the origin of red spirals: does assembly bias play a role?

The formation of the red spirals is a puzzling issue in the standard picture of galaxy formation and evolution. Most studies attribute the colour of the red spirals to different environmental effects. We analyze a volume limited sample from the SDSS to study the roles of small-scale and large-scale environments on the colour of spiral galaxies. We compare the star formation rate, stellar age and stellar mass distributions of the red and blue spirals and find statistically significant differences between them at 99.9% confidence level. The red spirals inhabit significantly denser regions than the blue spirals, explaining some of the observed differences in their physical properties. However, the differences persist in all types of environments, indicating that the local density alone is not sufficient to explain the origin of the red spirals. Using an information theoretic framework, we find a small but non-zero mutual information between the colour of spiral galaxies and their large-scale environment that are statistically significant (99.9% confidence level) throughout the entire length scale probed. Such correlations between the colour and the large-scale environment of spiral galaxies may result from the assembly bias. Thus both the local environment and the assembly bias may play essential roles in forming the red spirals. The spiral galaxies may have different assembly history across all types of environments. We propose a picture where the differences in the assembly history may produce spiral galaxies with different cold gas content. Such a difference would make some spirals more susceptible to quenching. In all environments, the spirals with high cold gas content could delay the quenching and maintain a blue colour, whereas the spirals with low cold gas fractions would be easily quenched and become red. This study has been done in collaboration with Suman Sarkar, and Apashanka Das

Green valley galaxies in the cosmic web: internal versus environmental quenching

We analyze the SDSS data to classify the galaxies based on their colour using a fuzzy set-theoretic method and quantify their environments using the local dimension. We find that the fraction of the green galaxies does not depend on the environment and $10\% - 20\%$ of the galaxies at each environment are in the green valley depending on the stellar mass range chosen. Approximately 10% of the green galaxies at each environment host an AGN. Combining data from the Galaxy Zoo, we find that $\sim 95\%$ of the green galaxies are spirals and $\sim 5\%$ are ellipticals at each environment. Only $\sim 8\%$ of green galaxies exhibit signs of interactions and mergers, $\sim 1\%$ have dominant bulge, and $\sim 6\%$ host a bar. We show that the stellar mass distributions for the red and green galaxies are quite similar at each environment. Our analysis suggests that the majority of the green galaxies must curtail their star formation using physical mechanism(s) other than interactions, mergers, and those driven by bulge, bar and AGN activity. We speculate that these are the massive galaxies that have grown only via smooth accretion and suppressed the star formation primarily through mass driven quenching. Using a Kolmogorov-Smirnov test, we do not find any statistically significant difference between the properties of green galaxies in different environments. We conclude that the environmental factors play a minor role and the internal processes play the dominant role in quenching star formation in the green valley galaxies. This study has been done in collaboration with Apashanka Das, and Suman Sarkar.

Amit Pathak

Theoretical study of infrared spectra of interstellar PAH molecules with N, NH & NH_2 incorporation

This work presents theoretical calculations of infrared spectra of nitrogen (N)-containing polycyclic aromatic hydrocarbon (PAH) molecules with the incorporation of N, NH, and NH_2 using density functional theory (DFT). The properties of their vibrationalmodes in 2–15 μm are investigated in relation to the Unidentified Infrared (UIR) bands. It is found that neutral PAHs, when incorporated with NH_2 and N (at inner positions), produce intense infrared bands at 6.2, 7.7, and 8.6 μm that have been normally attributed to ionized PAHs so far. The present results suggest that strong bands at 6.2 and 11.2 μm can arise from the same charge state of some N-containing PAHs, arguing that there might be some N-abundant astronomical regions where the 6.2 to 11.2 μm band ratio is not a direct indicator of the PAHs' ionization. PAHs with NH_2 and N inside the carbon structure show the UIR band features characteristic to star-forming regions as well as reflection nebulae (Class A), whereas PAHs with N at the periphery have similar spectra to the UIR bands seen in planetary nebulae and post-AGB stars (Class B). The presence of N atoms at the periphery of a PAH may attract H or H^+ to form N-H and N-H_2 bonds, exhibiting features near 2.9-3.0 μm, which are not yet observationally detected. The absence of such features in the observations constrains the contribution of NH and NH_2 substituted PAHs that could be better tested with concentrated observations in this range. However, PAHs with N without H either at the periphery or inside the carbon structure do not have the abundance constraint due to the absence of 2.9-3.0 μm features and are relevant in terms of positions of the UIR bands. Extensive theoretical and experimental studies are required to obtain deeper insight. This work has been done in collaboration with A. Vats, T. Onaka, M. Buragohain, I. Sakon, and I. Endo.

Chemical complexity of phosphorous bearing species in various regions of the Interstellar medium

Phosphorus-related species are not known to be as omnipresent in space as hydrogen, carbon, nitrogen, oxygen, and sulfur-bearing species. Astronomers spotted very few P-bearing molecules in the interstellar medium and circumstellar envelopes. Limited discovery of the P-bearing species imposes severe constraints in modeling the P-chemistry. In this paper, we carry out extensive chemical models to follow the fate of P-bearing species in diffuse clouds, photon-dominated or photodissociation regions (PDRs), and hot cores/corinos. We notice a curious correlation between the abundances of PO and PN and atomic nitrogen. Since N atoms are more abundant in diffuse clouds and PDRs than in the hot core/corino region, PO/PN reflects <1 in diffuse clouds, $=1$ in PDRs, and >1 in the late warm-up evolutionary stage of the hot core/corino regions. During the end of the post-warm-up stage, we obtain PO/PN >1 for hot core and <1 for its low-mass analog. We employ a radiative transfer model to investigate the transitions of some of the P-bearing species in diffuse cloud and hot core regions and estimate the line profiles. Our study estimates the required integration time to observe these transitions with ground-based and space-based telescopes. We also carry out quantum chemical computation of the infrared features of PH_3, along with various impurities. We notice that SO_2 overlaps with the PH_3 bending-scissoring modes around $\sim$ 1000-1100 cm^{-1}. We also find that the presence of CO_2 can strongly influence the intensity of the stretching modes around $\sim$ 2400 cm^{-1} of PH_3. This Work has been done in collaboration with M. Sil, S. Srivastav, B. Bhat, S.K. Mondal, P. Gorai, R. Ghosh, T. Shimonishi, S.K. Chakrabarti, and B. Sivaraman.

Bikash C. Paul

Dynamical Wormholes for Emergent Universe Scenario:

A flat emergent universe (EU) in Einstein gravity with non-linear equation of state (nEoS) is obtained in the usual four and in higher dimensions. The EU is evolved from an initial Einstein static universe (ESU) in the infinite past and there is no singularity. For a homogeneous Ricci scalar the shape function is determined to obtain a new class of dynamical wormholes that permits EU which emerged from the throat of the wormhole in the infinite past. An interesting observation is that nEoS $p = A\rho - B\sqrt{\rho}$ is equivalent to three different cosmic fluids which is identified with the barotropic fluids for a given A. We obtain EU models in flat, closed and open universes and probed the null energy condition (NEC). At the throat of the wormhole which is recognized as the seed of ESU, the NEC is tested for a given size of the neck. As the EU evolves from an asymptotic past and approaches $t = 0$, it is found that NEC does not respect. This triggers the onset of interactions at $t = t_i$, and a realistic flat EU scenario thus can be obtained in four and in higher dimensions. The origin of the ESU at the throat of the wormhole is also explored via a gravitational instanton mechanism. We compare the relative merits of dynamical wormholes for implementing such EU.

Anisotropic strange stars in Einstein Gauss-Bonnet Gravity with Finch-Skea metric:

A class of new anisotropic relativistic solutions are obtained in Einstein Gauss-Bonnet (EGB) gravity with Finch-Skea metric in the hydrostatic equilibrium. Using the relativistic solutions anisotropic stellar models for strange star are constructed with MIT Bag equation of state $p_r = \frac{1}{3}(\rho 4B)$ where B is the Bag constants. Considering the mass and radius of a known star PSR J0348+0432 we construct stellar models in the framework of higher dimensions. We also predict the mass and radius of stars for different model parameters. The Gauss-Bonnet coupling term α is found to play an important role in determining the density, pressure, anisotropy profiles and other features. The stability of the stellar models are probed analyzing the different energy conditions, variation of sound speed and adiabatic stability conditions inside the star. The central density and pressure of a star in EGB gravity are found to have higher values compared to that one obtains in Einstein gravity (α= 0). We also explore the effect of extra dimensions for the physical features of a compact object. Realistic stellar models are found for a given set of model parameters and $D = 5$ and $D = 6$ dimensions are taken too compare the results. For $D = 5$, it is found that $\alpha > 0$ or $\alpha < 0$ are permitted but in $D = 6$ only $\alpha < 0$ permitted for stars with Finch-Skea geometry. The best fit values of the model parameters are determined for a number of observed stars for their acceptability.

Ananta C. Pradhan

Study of UV bright sources in globular cluster NGC 4590 using Ultraviolet Imaging Telescope (UVIT) observations

We have studied ultraviolet (UV) bright sources in the Galactic globular cluster (GGC) NGC 4590 using Ultraviolet Imaging Telescope (UVIT) on-board the *AstroSat* satellite. Using UV-optical color-magnitude diagrams (CMDs), we have identified and characterized the sources of different evolutionary stages i.e., blue horizontal branch stars (BHBs), extremely blue horizontal branch stars (EHBs), blue straggler stars (BSs), variable stars, etc. We estimated effective temperature ($T_{\rm eff}$), gravity (log(g)), luminosity (L_{bol}), and hence the radius (R) of these hot stars by fitting spectral energy distribution (SED) with the help of stellar atmosphere models. Two new far-UV (FUV) bright cluster member stars situated near the core of the cluster have been detected; one of them is an EHB star and the other one is either in its post-blue hook evolutionary phase or in white dwarf phase. The evolutionary status of all the hot stars, identified in the cluster, has been investigated by using various evolutionary models. We find the massive and younger BSs are concentrated at the center of the cluster whereas the older and less massive BSs are distributed though out the cluster. The BSs normalized radial distribution seems to be bi-modal with a minimum located at $r_{\rm min} = 4.3\ r_c$. We calculated A^+ parameter of the cluster which is obtained using cumulative normalized radial distribution of horizontal branch stars (HBs) and BSs. We measured this value up to half-mass radius of the cluster to be +0.13, which indicates that NGC 4590 is one of the youngest clusters among dynamically intermediate age GGCs with a dynamical age of 0.423±0.096 Gyr. This work has been carried out in collaboration with Ranjan Kumar, M. Parthasarathy, Sonika Piridi, Santi Cassisi, Devendra K. Ojha, Abhisek Mohapatra, and Jayant Murthy

UVIT study of UV bright stars in the globular cluster NGC 4147Study of Structure of Our Galaxy Using Ultraviolet Star Counts of GALEX and UVIT-ASTROSAT Surveys

We present far ultraviolet (FUV) observations of globular cluster NGC 4147 using three FUV filters, BaF2 (F154W), Sapphire (F169M), and Silica (F172M) of Ultra-Violet Imaging Telescope (UVIT) on-board the *AstroSat* satellite. We confirmed the cluster membership of the UVIT observed sources using proper motions from Gaia data release 2 (GAIA DR2). We identified 37 blue horizontal branch stars (BHBs), one blue straggler star (BSS) and 15 variable stars using UV-optical color magnitude diagrams (CMDs). We find that all the FUV bright BHBs are second generation population stars. Using UV-optical CMDs, we identify two sub-populations, BHB1 and BHB2, among the UV-bright BHBs in the cluster with stars count ratio of 24:13 for BHB1 and BHB2. The effective temperatures ($T_{\rm eff}$) of BHB1 and BHB2 were derived using color-temperature relation of BaSTI-IAC zero-age horizontal branch (ZAHB). We found that BHB1 stars are more centrally concentrated than BHB2 stars. We also derive physical parameters of the detected FUV bright BSS by fitting younger age BaSTI-IAC isochrones on optical and UV-optical CMDs. This work is done in collaboration with Ranjan Kumar, Mudumba Parthasarathy, Devendra K. Ojha, Abhisek Mohapatra, Jayant Murthy, and Santi Cassisi.

Anirudh Pradhan

Quark stars in $f(R,T)$ gravity with an interacting quark equation of state

The current trend concerning dense matter physics at sufficiently high densities and low temperatures is expected to behave as a degenerate Fermi gas of quarks forming Cooper pairs, namely a color superconductor, in the core of compact objects. In this context, we study the anisotropy of quark stars (QSs) assuming the internal composition to be comprised of homogeneous, charge neutral 3- flavor interacting quark matter with $O(m_s^4)$ corrections. Using the equation of state (EoS) with the Tolman-Oppenheimer-Volkoff (TOV) structure equations, we perform numerical calculation for quark stars and determine the maximum mass-radius relation in the context of 4D Einstein-Gauss-Bonnet (EGB) gravity. In particular, we consider the effects of Gauss-Bonnet (GB) coupling constant on the diagrams related to mass-radius (M - R) relation and the mass-central mass density $(M - \rho_c)$ relation of QSs. We pay particular attention to the influence of the anisotropy in the equilibrium and stability of strange stars. We also study the other properties of QSs related to compactness and binding energy. Interestingly, our result provides circumstantial evidence in favor of super-massive pulsars in 4D EGB gravity. This work has been done in collaboration with T. Tangphati, A. Banerjee and S. Hanraj.

Electrically Charged Quark Stars in 4D Einstein-Gauss-Bonnet Gravity

In this work we study the properties of compact spheres made of a charged perfect fluid with a MIT bag model EoS for quark matter. Considering static spherically symmetric spacetime we derive the hydrostatic equilibrium equations in the recently formulated four dimensional Einstein-Gauss-Bonnet (4D EGB) gravity theory. In this setting, the modified TOV equations are solved numerically with the aim to investigate the impact of electric charge on the stellar structure. A nice feature of 4D EGB theory is that the Gauss-Bonnet term has a non-vanishing contribution to the gravitational dynamics in 4D spacetime. We therefore analyse the effects of Gauss-Bonnet coupling constant α and the charge fraction β on the mass-radius (M-R) diagram and also the mass-central density $(M - \rho_c)$ relation of quark stars. Finally, we conclude that depending on the choice of coupling constant one could have larger mass and radius compared with GR and can also be relevant for more massive compact objects due to the effect of the repulsive Coulomb force. This work has been done in collaboration with Jaun M. Z. Pretel, and A. Banerjee.

Anisur Rahaman

Bumblebee gravity with a Kerr-Sen-like solution and its Shadow

Lorentz-Violating (LV) scenario gets involved through a bumblebee field vector field B_μ. A spontaneous symmetry breaking allows the field to acquires a vacuum expectation value that generates LV into the system. A Kerr-Sen-like solution has been found out starting from the generalized form of a radiating stationery axially symmetric black-hole metric. We compute the effective potential offered by the null geodesics in the bumblebee rotating black-hole spacetime. The shadow has been sketched for different variations of the parameters involved in the system. A careful investigation has been carried out to study how the shadow gets affected when Lorentz violation enters into the picture. The emission rate of radiation has also been studied and how it varies with the LV parameter ℓ is studied scrupulously.

This work has been done in collaboration with S. K. Jha

A model of boson in $(1 + 1)$ dimension with the non-covariant masslike term for the gauge field

We consider the gauged model of Siegel type chiral boson with a Lorentz non-covariantmass-like term for the gauge fields which is found to be equivalent to a model of bosonwhere the kinetic term is like the kinetic term of Floreanini-Jackiw type chiral boson. Wecarry out the quantization of gauge non-invariant version this model in both the Lagrangianand Hamiltonian formulation. The quantization of the gauge-invariant version of this modelin the extended phase space also has been carried out in the Lagrangian formulation. Thegauge-invariant version of this model in the extended phase space is found to map onto thephysical phase space with the appropriate gauge fixing condition. BRST symmetry associ-ated with this model has been studied with different gauge fixing terms. It has been shownthat the same model shows off-shell as well as on-shell BRST invariance depending on thechoice of gauge fixing term. This work has been done in collaboration with S. Absar, and S. Ghoshal

Farook Rahaman

Thin accretion disks around traversable wormholes

In this paper, we aim to investigate various physical properties and characteristics of radiation emerging from the surface of the accretion disks, in a rotating traversable axially symmetric wormhole spacetime of the Teo class. We have studied the marginally stable orbits and accretion efficiency graphically, corresponding to different values of dimensionless spin parameter J/M^2 ranging from 0.2 to 1.5 and some values of the throat radius r_0, in comparison to the Kerr black hole with the same parameter values, and also tabulated the results. The energy flux radiated by the accretion disk $F(r)$, the temperature distribution $T(r)$ and the emission spectra $\nu L(\nu)$ is plotted, corresponding to varying values of the dimensionless spin parameter J/M^2 and throat radius r_0. Also, the critical frequency at which the luminosity attains its maximum value, for various values of the angular momentum of the wormhole J/M^2 and r_0 is tabulated. Lastly, we have employed ray-tracing technique, to produce the intensity map of the image of an accretion disk, as observed by an asymptotic observer, under two conditions: firstly when the disk is on the same side as the observer and we have also compared those with the images of an accretion disk in case of Kerr black hole with same parameters. Secondly, the images have been provided when the disk and observer are on opposite sides of the throat. This study may help to detect and distinguish wormhole geometries from other compact objects. This work has been done in collaboration with B Samanta, R Islam, T Manna, S Aktar, M Mondal.

Shadows of Lorentzian traversable wormholes

The prospect of identifying wormholes by investigating the shadows of wormholes constitute a foremost source of insight into the evolution of compact objects and it is one of the essential problems in contemporary astrophysics. The nature of the compact objects (wormholes) plays a crucial role on shadow effect, which actually arises during the strong gravitational lensing. Current Event Horizon Telescope observations have inspired scientists to study and to construct the shadow images of the wormholes. In this work, we explore the shadow cast by a certain class of rotating wormhole. To search this, we first compose the null geodesics and study the effects of the parameters on the photon orbit. We have exposed the form and size of the wormhole shadow and have found that it is slanted as well as can be altered depending on the different parameters present in the wormhole spacetime. We also constrain the size and the spin of the wormhole using the results from M87* observation, by investigating the average diameter of the wormhole as well as deviation from circularity with respect to the wormhole throat size. In a future observation, this type of study may help to indicate the presence of a wormhole in a galactic region. This work has been done in collaboration with N Singh, R Islam, T Manna,and S Aktar.

Chayan Ranjit

Analysis of different scenarios with new tsallis holographic dark energies and bulk viscous fluid in the framework of Chern−Simons modified gravity

In this work we perform an observational data analysis on the energy momentum squared gravity model. Possible solutions for matter density are obtained from the model and their cosmological implications are studied. Some recent observational data is used to constrain model parameters using statistical techniques. We have used the cosmic chronometer and SNe Type-Ia Riess (292) $H(z) - z$ data-sets in our study. Along with the data-sets we have also used baryon acoustic oscillation (BAO) peak parameter and cosmic microwave background (CMB) peak parameter to obtain bounds on the model parameters. Joint analysis of the data with the above mentioned parameters have been performed to obtain better results. For the statistical analysis we have used the minimization technique of the χ^2 statistic. Using this tool we have constrained the free parameters of the model. Confidence contours have been generated for the predicted values of the free parameters at the 66%, 90% and 99% confidence levels. Finally we have compared our analysis with the union2 data sample presented by Amanullah et al.,2010 and the recently published Pantheon data sample. Finally a multi-component model is investigated by adding dust to a general cosmological fluid with equation of state $w = -1/3$. The density parameters were studied and their values were found to comply with the observational results.This work has been done in collaboration with Sayeedul

Islam, Surajit Chattopadhyay, and Ertan Gudekli

Shantanu Rastogi

Accretion disc sizes from continuum reverberation mapping of AGN selected from the ZTF survey

The accretion disc-size estimates are presented for a sample of 19 active galactic nuclei (AGNs) using the optical g-, r-, and i-band light curves obtained from the Zwicky Transient Facility survey. All the AGNs have reliable supermassive black hole (SMBH) mass estimates based on previous reverberation mapping measurements. The multiband light curves are cross-correlated, and the reverberation lag is estimated using the Interpolated Cross-Correlation Function method and the Bayesian method using the JAVELIN code. As expected from the disc-reprocessing arguments, the g r band lags are shorter than the g i band lags for this sample. The interband lags for all, but five sources, are larger than the sizes predicted from the standard Shakura Sunyaev (SS) analytical model. We fit the light curves directly using a thin disc model implemented through the JAVELIN code to get the accretion disc sizes. The disc sizes obtained using this model are on an average 3.9 times larger than the prediction based on the SS disc model. We find a weak correlation between the disc sizes and the known physical parameters, namely the luminosity and the SMBH mass. In the near future, a large sample of AGNs covering broader ranges of luminosity and SMBH mass from large photometric surveys would be helpful in a better understanding of the structure and physics of the accretion disc. This work has been done in collaboration with V.K. Jha, R. Joshi, H. Chand, X. Wu, L.C. Ho, and Q. Ma.

A comparative study of the physical properties for a representative sample of Narrow and Broad-line Seyfert galaxies

A comparative study of the physical properties of a homogeneous sample of 144 Narrow line Seyfert 1 (NLSy1) and 117 Broad-line Seyfert 1 (BLSy1) galaxies are presented. These two samples are in a similar luminosity and redshift range and have optical spectra available in the 16th data release of Sloan Digital Sky Survey (SDSS-DR16) and X-ray spectra in either XMM-NEWTON or ROSAT. Direct correlation analysis and a principal component analysis (PCA) have been performed using ten observational and physical parameters obtained by fitting the optical spectra and the soft X-ray photon indices as another parameter. We confirm that the established correlations for the general quasar population hold for both types of galaxies in this sample despite significant differences in the physical properties. We characterize the sample also using the line shape parameters, namely the asymmetry and kurtosis indices. We find that the fraction of NLSy1 galaxies showing outflow signatures, characterized by blue asymmetries, is higher by a factor of about 3 compared to the corresponding fraction in BLSy1 galaxies. The presence of high iron content in the broad-line region of NLSy1 galaxies in conjunction with higher Eddington ratios can be the possible reason behind this phenomenon. We also explore the possibility of using asymmetry in the emission lines as a tracer of outflows in the inner regions of Active Galactic Nuclei. The PCA results point to the NLSy1 and BLSy1 galaxies occupying different parameter spaces, which challenges the notion that NLSy1 galaxies are a subclass of BLSy1 galaxies. This work has been done in collaboratio with V. K. Jha, H. Chand, V. Ojha, and A. Omar.

C. D. Ravikumar

Constraints on the minimum electron energy from X-ray spectral analysis of blazar PKS 2155-304

We report a novel method to constrain the photon energy down to a level where inverse Compton emission begins to contribute in the emission of blazars. The convex (concave upward) high-energy X-ray spectra of the blazar PKS 2155-304, observed by *XMM-Newton*, is generally assumed as an evidence for sub-dominant inverse Compton emission. The spectra can be well fitted by a superposition of two power-law contributions which imitate the emission due to synchrotron and inverse Compton processes. We show that this information supplemented with knowledge of the jet Doppler factor and magnetic field strength can be used to constrain the low-energy cutoff $\gamma_{\rm min} m_e c^2$ of the radiating electron distribution and the kinetic power $P_{\rm j}$ of the jet. We deduce these quantities through a statistical fitting of the broadband spectral energy distribution of PKS 2155-304 assuming synchrotron and synchrotron self Compton emission mechanisms. Our results favour a minimum Lorentz factor for the non-thermal electron distribution of $\gamma_{\rm min} \gtrsim 60$, with a preference for a value around $\gamma_{\rm min} \simeq 330$. The required kinetic jet power is of the order of $P_{\rm j} \sim 3 \times 10^{45}$ erg s^{-1} in case of a heavy, electron-proton dominated jet, and could be up to an order of magnitude less in case of a light, electron-positron dominated jet. Our best fit parameters for the source support the X-ray emitting part of blazar jets to be dominated by an electron-proton rather than an electron-positron composition. has been done in collaboration with Sitha K. Jagan, S. Sahayanathan, and Frank M. Rieger

Saibal Ray

Noncommutative black hole in the Finslerian spacetime Class

We study the behavior of the noncommutative radiating Schwarzschild black hole in the Finslerian spacetime. The investigation shows that black hole possesses either (i) two horizons, or (ii) a single horizon, or (iii) no horizon corresponding to a minimal mass. We obtain that the minimal mass significantly changes with the Finslerian parameter, keeping minimal horizon remain unchanged. It turns out that under Finslerian spacetime, the maximum temperature before cooling down to absolute zero varies with the Finslerian parameter. We then study the stability of the black hole by analyzing the specific heat and free energy. The energy conditions, their violation limit also scrutinized. Our findings suggest a stable black hole remnant, whose mass and size are uniquely determined in terms of the Finslerian parameter and noncommutative parameter χ. The physical relevance of these results are discussed in a brief. This has been studied in collaboration with S. Roy Chowdhury, D. Deb, F. Rahaman, and B.K. Guha

A semi-classical model of regular inflationary cosmology

Quantum-effective gravity must lead to a regularized cosmology and thereby by itself source and regulate the high energy inflaton fields required for an appropriate inflationary beginning of the Universe. Pursuing this premise, we involve in the generic code of extended theories of gravity in conceiving semi-classical imprinting of quantum effects into gravitation. Hence, we prescribe a general semi-classical procedure of constructing the regular, quantum-effective form of the spatially flat FLRW cosmology whereby two alternative classes of the admissible dynamics are distinguished. In this paper, we explore only the particular class holding a minimally inflationary de Sitter UV-phase. Curiously, the low energy phase of the newly modeled Universe recovers the conventional dynamics of loop quantum cosmology. However, unlike the loop quantum cosmology, the high energy phase of the newly conceived cosmology. This article is written collaboration with B. Paik, M. Khlopov,and M. Kalam .

Prabir Rudra

Thermodynamics of the apparent horizon in the generalized energy-momentum-squared cosmology

In this note, we explore the thermodynamic properties of the universe in the background of the generalized energy-momentum-squared gravity. We derive the energy density of matter from the non-standard continuity equation and use it in our analysis. We consider two types of models depending on the nature of coupling between curvature and matter and perform thermodynamic analysis on them using the cosmic apparent horizon. The models are kept as generic as possible from the mathematical point of view in order to gain a wide applicability of the work. In this work we have considered power law and exponential form of models. All the thermodynamic parameters are expressed in terms of the cosmic apparent horizon radius and its time derivatives and their time evolution are studied. By using temperature, heat capacity analysis and the evolution trend of Helmholtz free energy the conditions for thermodynamic stability of the models are derived. It is seen that our stability analysis considerably constrain the parameter space of the model. This work has been done in collaboration with Behnam Pourhassan.

Constraints on cubic and $f(P)$ gravity from the cosmic chronometers, BAO & CMB datasets : Use of machine learning algorithms

In this work we perform an observational data analysis on Einsteinian cubic gravity and $f(P)$ gravity with the objective of constraining the parameter space of the theories. We use the 30 point $z - H(z)$ cosmic chronometer data as the observational tool for our analysis along with the BAO and the CMB peak parameters. The χ^2 statistic is used for the fitting analysis and it is minimized to obtain the best fit values for the free model parameters. We have used the Markov chain Monte Carlo algorithm to obtain bounds for the free parameters. To achieve this we used the publicly available *CosmoMC* code to put parameter bounds and subsequently generate contour plots for them with different confidence intervals. Besides finding the Hubble parameter H in terms of the redshift z theoretically from our gravity models, we have exercised correlation coefficients and two *machine* *learning* models, namely the linear regression (LR) and artificial neural network (ANN), for the estimation of $H(z)$. For this purpose, we have developed a *Python* package for finding the parameter space, performing the subsequent statistical analysis and prediction analysis using machine learning. We compared both of our theoretical and estimated values of $H(z)$ with the observations. It is seen that our theoretical and estimated models from machine learning performed significantly well when compared with the observations.

This work has been done in collaboration with Kinsuk Giri.

Sunil Kumar S.

Numerical simulations of storage and thermometry of smallbiomolecular ions in a 16-pole ion trap and a 16-wire ion trap

This work focuses on numerical simulations of ion dynamics of small biomolecular ions ($m/z \sim 200$) under the influence of elastic collisions with a buffer gas in a 16-pole ion trap and a 16-wire ion trap. A comparison between effective potentials in these trap configurations is provided. Particular emphasis is placed on studying storage efficiency and ion temperature in both traps. The dependence of temperature on various trapping parameters is discussed. It is found that the optimum operating range in terms of storage efficiency in a wire trap is limited compared to that in a pole trap and exhibits higher sensitivity to various parameters at low temperatures. However, with a proper choice of the operating parameters, the wire trap can serve as a practical alternative to the conventional design of a multipole ion trap while providing the lateral optical access, which will open a new window for spectroscopic studies with such traps. This work has been done in collaboration with Rajeevan Gayathry, and M. Salvi,

Metastable states of Si^- *observed in a cryogenic storage ring*

We have used the Cryogenic Storage Ring (CSR) at the Max Planck Institute for Nuclear Physics to study the long-lived metastable states of the silicon anion. A Si^- beam of 58 keV kinetic energy was stored in the ultrahigh cryogenic vacuum of the CSR, employing only electrostatic deflection elements. We used laser systems at various wavelengths to infer information on the decay of the metastable anionic states by selective photodetachment. Our results give evidence of an excited anionic state for which we determine the extremely long lower lifetime limit of 5.7 h at 90% confidence level, consistent with theoretical predictions for the ^2D term. Furthermore, we find an average lifetime of $\tau = (22.2 \pm 2.5)\,\mathrm{s}$ for the weakly bound ^2P states, employing coincidence counting with a pulsed nanosecond laser at $2.45\,\mu\mathrm{m}$. Using a laser depletion technique, we produce a pure ground term $^4S_{3/2}\,\mathrm{Si}^-$ beam, and we quantify the fraction of ions in metastable states in our initial ion sample. We combine our experimental efforts with state-of-the-art multiconfiguration Dirac-Hartree-Fock calculations for the radiative lifetimes of all metastable levels of Si^-. We find these calculations to be in excellent agreement with our measurements and to improve previous efforts considerably. This work has been done in collaboration with D. Mull, F. Grussie, K. Blaum, S. George, J. Gock, M. Grieser, R. von Hahn et all.

Sanjay K. Sahay

Robust malware detection models: learning from adversarial attacks and defenses

The last decade witnessed an exponential growth of smartphones and their users, which has drawn massive attention from malware designers. The current malware detection engines are unable to cope with the volume, velocity, and variety of incoming malware. Thus the anti-malware community is investigating the use of machine learning and deep learning to develop malware detection models. However, research in other domains suggests that the machine learning/deep learning models are vulnerable to adversarial attacks. Therefore in this work, we proposed a framework to construct robust malware detection models against adversarial attacks. We first constructed twelve different malware detection models using a variety of classification algorithms. Then we acted as an adversary and proposed Gradient-based Adversarial Attack Network to perform adversarial attacks on the above detection models. The attack is designed to convert the maximum number of malware samples into adversarial samples with minimal modifications in each sample. The proposed attack achieves an average fooling rate of 98.68% against twelve permission-based malware detection models and 90.71% against twelve intent-based malware detection models. We also identified the list of vulnerable permissions/intents which an adversary can use to force misclassifications in detection models. Later we proposed three adversarial defense strategies to counter the attacks performed on detection models. The proposed Hybrid Distillation based defense strategy improved the average accuracy by 54.21% for twelve permission-based detection models and 59.14% for intent-based detection models. We also concluded that the adversarial-based study improves the performance and robustness of malware detection models and is essential before any real-world deployment.

This work has been done in collaboration with Hemant Rathore, Adithya Samavedhi, and Mohit Sewak

Robust android malware detection system against adversarial attacks Using Q-learning

Since the inception of Andoroid OS, smartphones sales have been growing exponentially, and today it enjoys the monopoly in the smartphone marketplace. The widespread adoption of Android smartphones has drawn the attention of malware designers, which threatens the Android ecosystem. The current state-of-the-art Android malware detection systems are based on machine learning and deep learning models. Despite having superior performance, these models are susceptible to adversarial attack. Therefore in this paper, we developed eight Android malware detection models based on machine learning and deep neural network and investigated their robustness against the adversarial attacks. For the purpose, we created new variants of malware using Reinforcement Learning, which will be misclassified as benign by the existing Android malware detection models. We propose two novel attack strategies, namely single policy attack and multiple policy attack using reinforcement learning for white-box and grey-box scenario respectively. Putting ourselves in adversary shoes, we designed adversarial attacks on the detection models with the goal of maximising fooling rate, while making minimum modifications to the Android application and ensuring that the apps functionality and behaviour does not change. We achieved an average fooling rate of 44.21% and 53.20% across all the eight detection models with maximum five modifications using a single policy attack and multiple policy attack, respectively. The highest fooling rate of 86.09% with five changes was attained against the decision tree based model using the multiple policy approach. Finally, we propose an adversarial defence strategy which reduces the average fooling rate by threefold to 15.22% against a single policy attack, thereby increasing the robustness of the detection models i.e. the proposed model can effectively detect variants (metamorphic) of malware. The experimental analysis shows that our proposed Android malware detection system using reinforcement learning is more robust against adversarial attacks. This work has been done in collaboration with Hemant Rathore, Piyush Nikam and Mohit Sew.

Gauranga C. Samanta

Inflationary cosmology- A new approach using Non-linear electrodynamics

We explore a new kind of NLED field as a source of gravity, which can accelerate the universe during the inflationary era. We propose a new type of NLED lagrangian which is characterised by two parameters: α (dimensionless parameter) and β (dimensionful parameter). We investigate the classical stability and the causality aspects of this model of inflationary expansion by demanding that the speed of the sound wave $c_s^2 > 0$ and $0 \leq c_s \leq 1$. Corresponding to $0 \leq c_s^2 \leq 1$, we find $0.382(1.828) \leq \beta B^2 \leq 0.288(1.469)$ for $\alpha = 0.1(1.0)$. The equation of state parameter $\omega = -1/3$ requires $\beta B^2 = 0.126(0.757)$ corresponding to $\alpha = 0.1(1.0)$. We find that the universe is accelerating i.e. $\ddot{a} > 0$ (which results in the deceleration parameter $q < 0$ (i.e. $\omega > -1/3$)), provided $\beta B^2 \geq 0.126(0.757)$. During inflation, the energy density ρ_B is found to be maximum and is given by $\rho_B^{max} = 0.65/\beta$. The magnetic field necessary to trigger the inflation is found to be $B \simeq \sqrt{\frac{0.4\rho_B^{max}}{0.65}} = 4 \times 10^{51}$ Gauss, where $\rho_B^{max}(\sim \rho_{inf}) = 10^{64}$ GeV^4 is the energy density of the universe during the inflationary expansion. Our model also predicts the e-fold number $N = 71(64)$ that the magnetic field at the end of inflation is about $B = 10^{-10}$ (10^{-4}) Gauss corresponding to $z = 0(1000)$ and this agrees quite well with the experimental prediction of the e-fold number. With $\alpha = 0.3(1.0)$ and $\beta B^2 = 0.3974(0.8239)$, we find the scalar spectral index $n_s = 0.9649$, consistent with the PLANCK 2018 CMB data. Further, with $\alpha = 0.3(1.0)$, $\beta B^2 = 0.3974(0.8239)$, we predicts the tensor-to-scalar ratio $r = 0.1417(0.1449)$ and the tensorial spectral index $n_T = -0.0177(-0.0181)$. This work has been done in collaboration with Payel Sarkar1, and Prasanta Kumar Das.

Deflection angle for charged wormhole in $f(R,T)$ gravity

This paper is focused on the study of charged wormholes which are combinations of Morris Thorne wormhole and Reissner-Nordström space-time. Gravitational lensing is an important tool which have been adopted to detect various objects like wormholes using the notion of deflection angle. In this work, we have evaluated deflection angle with and without using the strong field limit coefficients and compared the results. Further, exact charged wormhole solutions are obtained in $f(R,T)$ gravity and the nature of the energy conditions is examined. This work has been done in collaboration with Nisha Godani.

Biplob Sarkar

Looking at the high-energy X-ray universe- An Overview

X-ray astronomy started in the early 1960s and since then, the X-ray range of electromagnetic radiation has produced a great deal of astronomical information about the high-energy universe. We begin this article by giving a brief introduction to X-ray astronomy. We then provide a concise explanation of the emission and detection of X-rays from astronomical systems and discuss some of the known sources of high-energy X-rays in the universe. We also describe the capabilities of the X-ray missions in the past and X-ray missions that are currently underway. Finally, we discuss some of the upcoming X-ray satellites and present the concluding remarks. This work has been done in collaboration with Bitopan Das, Biplob Sarkar, and Ankur Nath.

An Effective Curriculum and Activity Based Teaching-learning in College Education

This chapter describes the general term 'curriculum' and provides an overview of college education. Here we discuss the various elements of an effective college education curriculum. Again, in recent years, activity based teaching-learning (ABTL) has proven to be an effective pedagogy for students to become actively involved in the learning process. This paper also describes the ABTL approach to college education and details the strengths and weaknesses of this approach in relation to college education.

Rathin Sarma

Evidence for coronal temperature variation in Seyfert 2 ESO 103–035 using NuSTAR observations

We report flux-resolved spectroscopic analysis of the active galactic nucleus (AGN) ESO 103–035 using *NuSTAR* observations. Following an earlier work, we fit the spectra using a thermal Comptonization model with a relativistic reflection component to obtain estimates of the coronal temperature for two flux levels. The coronal temperature was found to increase from $24.0^{+6.8}_{-3.4}$ to $55.3^{+54.6}_{-7.2}$ keV (errors at 1-σ confidence level) as the flux increased from 9.8 to 11.9×10^{-11} erg cm^{-2} s^{-1} in the 3–78 keV band. A marginal variation in the high energy photon index allows for both, a non-varying optical depth and for the optical depth to have varied by a factor of $\sim$2. This is in contrast to a previous work on *NuSTAR* flux resolved spectroscopy of the AGN, Ark 564, where the temperature was found to decrease with flux along with a 10% variation in the optical depth. The results maybe understood in a framework where AGN variability is either dominated by coronal heating variation leading to correlated increase of temperature with flux and the opposite effect being seen when the variability is dominated by changes in the seed photon flux.

This work has been done in collaboration with Samuzal Barua, V. Jithesh, Ranjeev Misra, Gulab C Dewangan, and Biman J Medhi.

Asoke K. Sen

1. Polarimetric and photometric observations of CB54, with analysis of four other dark clouds

We present the results of our BVR-band photometric and R-band polarimetric observations of 40 stars in the periphery of the dark cloud CB54. From different photometric data, we estimate E(B− V) and E(J− H). After involving data from other sources, we discuss the extinction variations towards CB54.We reveal two main dust layers: a foreground, E(−) $\approx$ 0.1mag, at $\sim$ 1 200 pc and an extended layer, E(B− V) $\geq$ 0.3 mag, at $\sim$ 1 .5 kpc. CB54 belongs to the latter. Based on these results, we consider the reason for the random polarization map that we have observed for CB54. We find that the foreground is characterized by low polarization (P $\leq$ 0.5 per cent) and a magnetic field parallel to the Galactic plane. The extended layer shows high polarization (P up to 5−7 per cent). We suggest that the field in this layer is nearly perpendicular to the Galactic plane and both layers are essentially inhomogeneous. This allows us to explain the randomness of polarization vectors around CB54 generally. The data − primarily observed by us in this work for CB54, by A. K. Sen and colleagues in previous works for three dark clouds CB3, CB25 and CB39, and by other authors for a region including the B1 cloud are analysed to explore any correlation between polarization, the near-infrared, E(J-H), and optical, E(B-V), excesses, and the distance to the background stars. If polarization and extinction are caused by the same set of dust particles, we should expect good correlations. However, we find that, for all the clouds, the correlations are not strong. This work has been done in collaboration with V. B. Ilin, M. S. Prokopjeva and R. Gupta.

Ranjan Sharma

Anisotropic generalization of Buchdahl bound for specific stellar models

Anisotropy is one factor that appears to be significantly important in the studies of relativistic compact stars. The objective of the current investigation is to obtain a maximum permissible compactness of a self-gravitating anisotropic compact stellar object. In our work, we make a generalization of the Buchdahl limit by incorporating an anisotropic effect for a selected class of exact solutions describing anisotropic stellar objects. For physically reasonable stellar configurations, the generalized bound is obtained by demanding that the central pressure must not diverge. In the isotropic case of a homogeneous distribution, we regain the Buchdahl bound $2M/R \leq 8/9$. Our investigation shows a direct link between the maximum allowed compactness and pressure anisotropy vis-a-vis geometry of the associated 3-space. . This work is done in collaboration with Arpita Ghosh, Soumik Bhattachary and Shyam Das.

Gyan P. Singh

Dynamical behaviours of Chaplygin gas, cosmological and gravitational 'constants' with cosmic viscous fluid in Bianchi type V space-time geometry

This paper is devoted to study modified Chaplygin gas and cosmological 'constant' as candidates of dark energy in the presence of cosmic viscous fluid with reference to the Bianchi type V space-time geometry. To represent a more viable cosmological model, variation of gravitational 'constant' is also considered. Precise solutions of equations of field have been acquired, where scale factors expand as monomial functions of cosmic time. Further, by use of graphical representation, behaviours of various parameters are also examined. This work has been done in collaboration with S. Kotambkar, and R. K. Kelkar.

Bianchi-I cosmology with generalised Chaplygin gas and periodic deceleration parameter

We investigate the Bianchi-I cosmological model in presence of generalised Chaplygin gas, variable gravitational and cosmological constant. The exact solutions of Einstein field equations are obtained with time varying periodic deceleration parameter. The graphical representation method has been used to discuss the physical and dynamical behaviour of the model. Further, the stability and physical acceptability of the obtained solutions have been investigated. Most of the parameters show periodic behaviour in this study due to the presence of cosine function in the deceleration parameter. In all cases, pressure is negative, which leads us to late time expansion of the universe. The considered models are found to be stable. This Work has been done in collaboration with Nikhil Hulke1,and B K Bishi.

Harinder P. Singh

it Optical Studies of RBS 0490 and SDSS J075939.79+191417.3

We present optical photometric and spectroscopic observations of two Cataclysmic Variables (CVs), namely RBS 0490 and SDSS J075939.79+191417.3. The optical variations of RBS 0490 have been found to occur at the period of 1.689±0.001 hr which appears to be a probable orbital period of the system. Present photometric observations of SDSS J075939.79+191417.3 confirm and refine the previously determined orbital period as 3.14240928±0.00000096 hr. The presence of long-duration eclipse features in the light curves of SDSS J075939.79+191417.3 indicates eclipses might be due to an accretion disc and bright spot. The orbital inclination of SDSS J075939.79+191417.3 is estimated to be $\sim 78^\circ$ using the eclipse morphology. The phased-light curve variations during the orbital cycle of RBS 0490 provide evidence of the emission from an independent second accretion region or a second fainter pole. Optical spectra of RBS 0490 and SDSS J075939.79+191417.3 show the presence of strong Balmer, weak He II (λ4686) emission lines, along with the detection of strong $H\beta$ emission lines with a large value of equivalent width. The characteristic features of RBS 0490 seem to favour low-field polars, while SDSS J075939.79+191417.3 appears to be similar to the non-magnetic systems. This work has been done in collaboration with Arti Joshi, J. C. Pandey, Nikita Rawat, Ashish Raj, Wei Wang, and Harinder P. Singh.

First detection of a magnetic field in low-luminosity B[e] stars

We report the first detection of the magnetic field in a star of FS CMa type, a subgroup of objects characterized by the B[e] phenomenon. The split of magnetically sensitive lines in IRAS 17449+2320 determines the magnetic field modulus of 6.2 ± 0.2 kG. Spectral lines and their variability reveal the presence of a B-type spectrum and a hot continuum source in the visible. The hot source confirms GALEX UV photometry. Because there is a lack of spectral lines for the hot source in the visible, the spectral fitting gives only the lower temperature limit of the hot source, which is 50 000 K, and the upper limit for the B-type star of 11 100 K. The V/R ratio of the Hα line shows quasiperiodic behavior on timescale of 800 days. We detected a strong red-shifted absorption in the wings of Balmer and Oi lines in some of the spectra. The absorption lines of helium and other metals show no, or very small, variations, indicating unusually stable photospheric regions for FS CMa stars. We detected two events of material infall, which were revealed to be discrete absorption components of resonance lines.

The discovery of the strong magnetic field together with the Gaia measurements of the proper motion show that the most probable nature of this star is that of a post-merger object created after the leaving the binary of the birth cluster. Another possible scenario is a magnetic Ap star around Terminal-Age Main Sequence (TAMS). On the other hand, the strong magnetic field defies the hypothesis that IRAS 17449+2320 is an extreme classical Be star. Thus, IRAS 17449+2320 provides a pretext for exploring a new explanation of the nature of FS CMa stars or, at least, a group of stars with very similar spectral properties. This work has been done in collaboration with D. Korcakova, F. Sestito, N. Manset, P. Kroupa et all.

Monika Sinha

Baryonic dense matter in view of gravitational-wave observations

The detection of gravitational waves (GWs) from the merger of binary neutron star (NS) events (GW170817 and GW190425) and subsequent estimations of tidal deformability play a key role in constraining the behaviour of dense matter. In addition, massive NS candidates ($\sim 2M_{\odot}$) along with NICER mass−radius measurements also set sturdy constraints on the dense matter equation of state. Strict bounds from GWs and massive NS observations constrain the theoretical models of nuclear matter comportment at large density regimes. On the other hand, model parameters providing the highly dense matter response are bounded by nuclear saturation properties. This work analyses coupling parametrizations from two classes based on covariant density functional models: non−linear and density−dependent schemes. Considering these constraints together, we study possible models and parametrization schemes with the feasibility of exotic degrees of freedom in dense matter which go well with the astrophysical observations as well as the terrestrial laboratory experiments. We show that most parametrizations with non-linear schemes do not support the observations and experiments while density-dependent scheme goes well with both. Astrophysical observations are well explained if the inclusion of heavier non-strange baryons is considered as one fraction of the dense matter particle spectrum. This work has been done in collaboration with Vivek B.Thapa, and Anil Kumar.

Influence of nuclear symmetry energy slope on compact stars with Δ-admixed hypernuclear matter

In this work, we study the effects of nuclear symmetry energy slope on neutron star dense matter equation of state and its impact on neutron star observables (mass-radius, tidal response). We construct the equation of state within the framework of covariant density functional theory implementing coupling schemes of non-linear and density-dependent models with viability of heavier non-nucleonic degrees of freedom. The slope of symmetry energy parameter ($L_{\rm sym}$) is adjusted following density-dependence of isovector meson coupling to baryons. We find that smaller values of $L_{\rm sym}$ at saturation favour early appearance of Δ-resonances in comparison to hyperons leading to latter's threshold at higher matter densities. We also investigate the dependence of $L_{\rm sym}$ on tidal deformability and compactness parameter of a 1.4 $M_{\odot}$ neutron star for different equation of states and observe similar converging behaviour for larger $L_{\rm sym}$ values. This work has been done in collaboration with Vivek B. Thapa.

Parijat Thakur

AstroSat Observation of 2016 outburst of H 1743–322

We present the detection of type C quasi-periodic oscillation (QPO) along with upper harmonic at respective frequencies of $\sim$ 0.6 Hz and $\sim$ 1.2 Hz in the single AstroSat observation taken during the 2016 outburst of the low-mass black hole X-ray binary H 1743–322. These frequencies are found to be shifted by $\sim$ 0.4 Hz for the QPO and $\sim$ 0.8 Hz for the upper harmonic with respect to that found in the simultaneous *XMM-Newton* and *NuSTAR* observation taken five days later than the AstroSat observation, indicating a certain geometrical change in the system. However, the centroid frequency of the QPO and the upper harmonic do not change with energy, indicating the energy-independent nature. The decreasing trend in the fractional rms of the QPO with energy is consistent with the previous results for this source in the low/hard state. The value of the photon index ($\Gamma \sim 1.67$) also indicates that the source was in the low/hard state during this particular observation. In addition, similar to the *XMM-Newton* observations during the same outburst, we find a hard lag of $\sim$ 21 ms in the frequency range of $\sim 1-5$ Hz. The log-linear trend between the averaged time lag and energy indicates the propagation of fluctuations in the mass accretion rate from outer part of the accretion disk to the inner hot regions. This part of the work is published in the Journal of Astrophysics and Astronomy (JApA), 2021, 42, 38. This work is done in collaboration with Swadesh Chand, V. K. Agrawal, G. C. Dewangan, and Prakash Tripathi,

S. K. Tripathy

Cosmological models with a hybrid scale factor

In this paper, we present some cosmological models with a hybrid scale factor (HSF) in the framework of general relativity (GR). The HSF fosters an early deceleration as well as a late-time acceleration and mimics the present Universe. The dynamical aspects of different cosmological models with HSF in the presence of different matter fields have been discussed. This work done is in collaboration with B. Mishra, Saibal Ray and M. Khlopov.

Role of extended gravity theory in matter bounce dynamics

In this work, we have studied some bouncing cosmologies in the frame work of $f(R,T)$ gravity. The bouncing scenario has been formulated to avoid the big bang singularity. The physical and geometrical parameters are investigated. The effect of the extended gravity theory on the dynamical parameters of the model has been investigated. It is found that, the $f(R,T)$ gravity parameter affects the cosmic dynamics substantially. We have also, tested the model through the calculation of the cosmographic coefficients and the $Om(z)$ parameter. A scalar field reconstruction of the bouncing scenario is also carried out. The stability of the model are tested under linear, homogeneous and isotropic perturbations This work done is in collaboration with A. S. Agrawal, S. Pal, and B. Mishra.

Sudhaker Upadhyay

4D AdS Einstein-Gauss-Bonnet black hole with YangMills field and its thermodynamics

We derive an exact black hole solution for the Einstein-Gauss- Bonnet gravity with Yang-Mills field in $4D$ AdS spacetime and investigate its thermodynamic properties to calculate exact expressions for the black hole mass, temperature, entropy and heat capacity. The thermodynamic quantities get modification in the presence of Yang-Mills field, however, entropy remains unaffected by the Yang-Mills charge. The solution exhibits P_ν criticality and belongs to the universality class of Van der Waals fluid. We study the effect of GaussBonnet coupling and Yang Mills charge on the critical behaviour and black hole phase transition. We observe that the values of critical exponents increase with the YangMills charge and decrease with the GaussBonnet coupling constant. This work is done in collaboration with D. V. Singh, B. K. Singh.

Thermodynamics of galaxy clusters in modified Newtonian potential

We study the thermodynamics of galaxy clusters in a modified Newtonian potential motivated by a general solution to Newton's 'sphere-point' equivalence theorem. We obtain the N particle partition function by evaluating the configurational integral while accounting for the extended nature of galaxies (via the inclusion of the softening parameter ϵ into the potential energy function). This softening parameter takes care of the Galaxy-halos whose effect on structuring the shape of the galactic disc has been found recently. The spatial distribution of the particles (galaxies) is also studied in this framework. A comparison of the new clustering parameter b_+ to the original clustering parameters is presented in order to visualize the effect of the modified gravity. We also discuss the possibility of system symmetry breaking via the behavior of the specific heat as a function of temperature. This work is done in collaboration with A.W. Khanday,and P. A. Ganai.

Anisul Ain Usmani

Large Heavy Magnetic Neutron stars

We systematically study the properties of pure nucleonic and hyperonic magnetic stars using a density-dependent relativistic mean field (DD-RMF) equations of state. We explore several parameter sets and hyperon coupling schemes within the DD-RMF formalism. We focus on sets that are in better agreement with nuclear and other astrophysical data, while generating heavy neutron stars. Magnetic field effects are included in the matter equation of state and in general relativity solutions, which in addition fulfill Maxwells equations. We find that pure nucleonic matter, even without magnetic field effects, generates neutron stars that satisfy the potential GW190814 mass constraint; however, this is not the case for hyperonic matter, which instead only satisfies the more conservative 2.1 $M_\odot$ constraint. In the presence of strong but still somehow realistic internal magnetic fields $\approx 10^{17}$ G, the stellar charged particle population re-leptonizes and de-hyperonizes. As a consequence, magnetic fields stiffen hyperonic equations of state and generate more massive neutron stars, which can satisfy the possible GW190814 mass constraint but present a large deformation with respect to spherical symmetry. This work is done in collaboration with I. A. Rather, U. Rahaman, V. Dexheimer,and S. K. Patra.

Large Rotating Neutron stars with Quark cores

The rotating neutron star properties are studied with a phase transition to quark matter. The density-dependent relativistic mean-field model (DD-RMF) is employed to study the hadron matter, while the Vector-Enhanced Bag model (vBag) model is used to study the quark matter. The star matter properties like mass, radius, the moment of inertia, rotational frequency, Kerr parameter, and other important quantities are studied to see the effect on quark matter. The maximum mass of rotating neutron star with DD-LZ1 and DD-MEX parameter sets is found to be around $3M_\odot$ for pure hadronic phase and decreases to a value around $2.6M_\odot$ with phase transition to quark matter, which satisfies the recent GW190814 possible maximum mass constraint, implying that the secondary component of GW190814 could be a fast-rotating hybrid star. For DDV, DDVT, and DDVTD parameter sets, the maximum mass decreases to satisfy the $2M_\odot$. The moment of inertia calculated for various DD-RMF parameter sets decreases with the increasing mass satisfying constraints from various measurements. Other important quantities calculated also vary with the bag constant and hence show that the presence of quarks inside neutron stars can also allow us to constraint these quantities to determine a proper EoS. Also, the theoretical study along with the accurate measurement of uniformly rotating neutron star properties may offer some valuable information concerning the high-density part of the equation of state. This work is done in collaboration with I. A. Rather, U. Rahaman, M. Imran, H. C. Das, and S. K. Patra.

Murli M. Verma

Power-law inflation in the $f(R)$ gravity

We investigate a form of $f(R) = R^{1+\delta}/R_c^\delta$ and study the viability of the model for inflation in the Jordan and the Einstein frames. We have extended this form to $f(R) = R + R^{1+\delta}/R_c^\delta$ in an attempt to solve the problems of the former model. This model is further analysed by using the power spectrum indices of the inflation and the reheating temperature. During the inflationary evolution, the model predicts a value of δ parameter very close to one ($\delta = 0.98$), while the reheating temperature $T_{re} \sim 10^{16}$ GeV at $\delta = 0.98$ is consistent with the standard approach to inflation and observations. We calculate the slow roll parameters for the minimally coupled scalar field within the framework of our models. It is found that the values of the scalar spectral index and tensor-to-scalar ratio are very close to the recent observational data, including those released by Planck 2018. Further, we find the scalar spectral index, tensor-to-scalar ratio are exactly same in the first model because the Jordan and the Einstein frames are conformally equivalent. We also attempt to constraint through the non-Gaussianity parameter. This work is done in collaboration with Ajay Kumar Sharma.

Jaswant Kumar Yadav

Hi constraints from the cross-correlation of eBOSS galaxies and Green Bank Telescope intensity maps

We present the joint analysis of Neutral Hydrogen (H_I) Intensity Mapping observations with three galaxy samples: the Luminous Red Galaxy (LRG) and Emission Line Galaxy (ELG) samples from the eBOSS survey, and the WiggleZ Dark Energy Survey sample. The H_I intensity maps are Green Bank Telescope observations of the redshifted 21cm emission on $100 deg^2$ covering the redshift range $0.6 < z < 1.0$. We process the data by separating and removing the foregrounds present in the radio frequencies with FASTI ICA. We verify the quality of the foreground separation with mock realizations, and construct a transfer function to correct for the effects of foreground removal on the HI signal. We cross-correlate the cleaned HI data with the galaxy samples and study the overall amplitude as well as the scale dependence of the power spectrum. We also qualitatively compare our findings with the predictions by a semianalytical galaxy evolution simulation. The cross-correlations constrain the quantity $\Omega_{H_I} b_{H_I} r_{H_I,opt}$ at an effective scale k_{eff}, where Ω_{H_I} is the HI density fraction, b_{HI} is the HI bias, and $r_{HI,opt}$ the galaxyhydrogen correlation coefficient, which is dependent on the HI content of the optical galaxy sample. At $k_{eff} = 0.31h/Mpc^{-1}$ we find $\Omega_{HI} b_{HI} r_{HI,Wig} = [0.58 \pm 0.09(stat) \pm 0.05(sys)] \times 10^3$ for GBT-WiggleZ, $\Omega_{HI} b_{HI} r_{HI,Wig} = [0.40 \pm 0.09(stat) \pm 0.04(sys)] \times 10^3$ for GBT-ELG, and $\Omega_{HI} b_{HI} r_{HI,Wig} = [0.35 \pm 0.08(stat) \pm 0.03(sys)] \times 10^3$ for GBT-LRG at $z \approx 0.8$. We also report results at $k_{eff} = 0.24$ and $k_{eff} = 0.48hMpc^{-1}$. With little information on HI parameters beyond our local Universe, these are amongst the most precise constraints on neutral hydrogen density fluctuations in an underexplored redshift range. This work is done in collaboration with LauraWolz, Alkistis Pourtsidou, KiyoshiW.Masui, Tzu-ChingChang, Julian E. Bautista, et al.

IUCAA CENTRES FOR ASTRONOMY RESEARCH AND DEVELOPMENT (ICARDs)

Department of Physics, Cooch Behar Panchanan Barma University (CBPBU): Activities from 01 April 2021 till 31 March 2022

Coordinator:
Ranjan Sharma

Area of Research

Theoretical astro-particle physics and cosmology

Compact stars; Exact solutions; Modified theories of gravity; Dark matter; Gravitational collapse.

The Department of Physics, CBPBU has introduced General Relativity as one of the Generic Elective papers (2.5 credits) and Astro-particle physics and Cosmology (15 credits) as Discipline Centric Elective papers in its CBCS syllabus for post-graduate students.

- **Colloquia/Seminars:**

1. Seminar talk delivered by Dr Kanak Saha, Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, Govt. of India on 10 December 2021.
   Title of the talk: The Extraordinary Escape of Extreme-UV Photons.
2. Seminar talk delivered by Prof. Mehedi Kalam, Department of Physics, Aliah University on 04 March 2022.
   Title of the talk: Relativity, wormhole and dark matter.

Publications using ICARD facilities:

1. Ranjan Sharma, Arpita Ghosh, Soumik Bhattacharya and Shyam Das (2021), Anisotropic generalization of Buchdahl bound for specific stellar models, Eur. Phys. J C, 81,1-5.
2. Shyam Das, Bikram Keshari Parida and Ranjan Sharma (2022), Estimating tidal Love number of a class of Compact Stars, Eur. Phys. J C, 82: 136.
3. Bikash Chandra Paul, Shyam Das and Ranjan Sharma (2022), Anisotropic Compact Objects with the colour-flavour-locked equation of state in Finch and Skea geometry, Eur. Phys. J Plus (to appear).
4. A Saha, K B Goswami and *P K Chattopadhyay (2021),* Anisotropic star in Vaidya-Tikekar model admitting MIT bag model equation of state in pseudo-spheroidal geometry, *Astrophys. Space Sci.* 366, l:98
5. K B Goswami, A Saha and *P K Chattopadhyay (2022),* Anisotropic compact star in modified Vaidya-Tikekar model admitting new solutions and maximum mass, Pramana-j phys. (to appear).

- **Outreach programmes, including public lectures/sky watch arranged by ICARD, etc:**

1. Ranjan Sharma participated in the Gravitex2021, an International Conference organized by the Astrophysics Research Centre, University of KwaZulu-Natal, Durban, South Africa and delivered a talk during 9-12 August 2021.
2. Ranjan Sharma delivered a talk as an invited speaker at the High Energy Cosmic Ray Research Centre, the University of North Bengal, on 15 March 2022.

- **Honours/distinctions/awards, etc. received by persons connected with ICARD:**

The ICARD, CBPBU arranged a felicitation programme on 10 December 2021 to honour Dr Kanak Saha, IUCAA, recipient of the Shanti Swaroop Bhatnagar Prize 2021 in Physical Science. The Hon'ble Vice-Chancellor, CBPBU, Registrar, CBPBU, Dean of Faculty of Post-Graduate Studies in Science, Technology and Vocational Studies and Dean, Faculty of Post-Graduate Studies in Arts, Fine Arts, Performing Art and Traditional Art Forms were present to grace the occasion. It is noteworthy that Dr Kanak Saha is a Visiting Professor at the Department of Physics, CBPBU.

Dr Kanak Saha, recipient of the Shanti Swarup Bhatnagar Prize 2021 in Physical Science, being felicitated by the Hon'ble Vice-Chancellor, Cooch Behar Panchanan Barma University.

Physics Department, North Bengal University, Siliguri, West Bengal

Coordinator:
Professor B. C. Paul

Research Area

Relativistic Astrophysics, Cosmology, Compact Objects, DATA analysis of X-ray Sources, Pulsar, Non-linear Dynamics

DATA Centre Activities

Research Scholars are engaged to Analyse X-ray Data of NASA to investigate Different Pulsars. At present Six Research Scholars are engaged in doing research using the facilities of the DATA centre. It is proposed to use ASTROSAT-data from IUCAA in coming days.

- **Seminar/Symposiums**

ICARD organized the following webinar during pandemic

1. International Seminar on Astrophysics and Cosmology (March 03, 2022)

   The International Seminar on Astrophysics and Cosmology is the first one day international seminar organized by ICARD at Physics Department, North Bengal University (NBU). The eminent cosmologists Prof. Mark Trodden (USA) delivered on "The many Incarnation of Dark Energy", Prof. K. K. Nandi (Russia) "Gravitational Time advancement", and from IUCAA Pune Prof. Dipankar Bhattacharyya "Science from ASTROSAT : New Results on Compact Objects", Dr. Kanak Saha "Probing Early Galaxy Formation using ASTROSAT UV Deep Field". The International seminar was inaugurated by Vice- Chancellor of NBU, Dr. Subires Bhattacharyya, Dean of Science Faculty Dr. Subhash Chandra Roy, Coordinator ICARD, NBU Prof. B. C. Paul, and Head, Department of Physics, Dr. P. Mali. About 192 motivated B. Sc. and M. Sc students from different universities and colleges attended the program in addition to research scholars and faculties showed interest. The ICARD made an arrangement for accommodating all via google meet as well as live you tube streaming platforms. It will give a good exposure of our students, Research Scholar and teachers with the active scientists. Dr. B. C. Paul coordinated the seminar with Research Fellows of the Department Sagar Dey and Anirban Chanda as secretary.

2. Prof. S. G. Ghosh, CTP Jamia Miiia University, New Delhi delivered Lecture on Shadow of Black holes (Mar 22, 2021). It was organized online and attended by students and visitors of ICARD, NBU.

3. Recent Advances in Astrophysics and Cosmology (Mar, 24-25, 2021) :

   There are more than 150 participants. We have arranged online platform as well as you tube live streaming so that all are accommodated in the Program. The seminar was inaugurated by the Director of IUCAA, Prof. Somak Raychaudhury and delivered a Keynote address. The invited speakers were Dr. Kanak Saha, Dr. Farook Rahaman. Profs. Murli M. Verma of Lucknow University and P. K. Sahaoo of BITS Pilani Hyderabad Campus chaired the sessions.

Publications using ICARD facilities

1. Skyrme Fluid in Anisotropic Universes with a Cosmological Constant - B. C. Paul, R. Sengupta, P. Paul and S. Ray, *accepted in* Pramana, A Journal of Physics (2022)
2. Cosmology in $f(R,T)$ gravity with a varying deceleration parameter, A. Chanda and B. C. Paul, IJGMMP-D-20-00551 (2020)
3. Late time cosmology in f (R, G)-gravity with interacting fluids - B. C. Paul, A Chanda, S Maharaj, A Beesham, Class. & Quantum Grav. (2022) accepted
4. Bianchi-I anisotropic universe with Barrow holographic dark energy - B. C. Paul, B. C. Roy, A. Saha, The European Physical Journal C 82, 1-7 (2022)
5. Wormholes in f(R, T) – gravity with density dependent B parameter in SQM – R. Deb, P. Mandal, B. C. Paul, Euro Physics J Plus (2022)
6. R\'enyi Holographic Dark Energy Models In Multidimensional Universe - A. Saha, A. Chanda, S. Dey, S. Ghosh, B C Paul, IJGMMP, 19, 2250043 (2022)
7. Reconstruction of modified Gauss–Bonnet gravity for emergent universe - BC Paul, SD Maharaj, A Beesham, Int. Journal of Modern Physics D, 2250045 (2022)
8. Asymptotic linear nonlinear duality, indeterminism and mathematical intelligence - Dhurjati Prasad Datta, Chaos, Solitons and Fractals, 152 (2021) 111457
9. Renyi holographic dark energy in higher dimension Cosmology - A. Saha, S. Ghose, A. Chanda, B. C. Paul, Annals of Physics, 426, 168403 (2021)
10. Traversable wormholes in the galactic halo with MOND and non-linear equation of state - B. C. Paul, Classical and Quantum Gravity 38 (14), 145022 (2021)
11. Emergent Universe in D ⊗ 4 dimensions with Dynamical Wormholes - Bikash Chandra Paul, Euro Phys. J C, 81, 776 (2021)
12. Accelerating Universe in Higher Dimensional Space Time -an alternative approach - Dibyendu Panigrahi, Bikash Chandra Paul, Sujit Kumar Chatterjee, Eur. Phys. J. Plus (2021) 136:771
13. Cosmological models in R^2 gravity with hybrid expansion law - P S Debnath and B C Paul, International Journal of Geometric Methods in Modern Physics. 18, No. 09, 2150143 (2021)
14. Existence of traversable wormholes with modified gravity and non-linear equation of state - Bikash Chandra

Paul, *Class. Quantum Grav.* 38 145022 (2021)

15. Timing and spectral properties of Be/Xray pulsar 4U 1901+03 during 2019 outburst – Binay Rai and B C. Paul, Astrophysics and Space Sci., 366, 84 (2021)

16. Study of Gravastars in Rastall gravity-S. Ghosh, S. Dey, A. Das, A. Chanda, B. C. Paul Accepted in *JCAP 07, 004 (2021).*

17. Morris-Thorne Wormholes in the modified f(R, T) gravity -Anirban Chanda, Sagar Dey, Bikash Chandra Paul, *General Relativity and Gravitation*, 53, 78 2021)

18. Comprehensive broadband study of accreting neutron stars with Suzaku Is there a bi-modality in the X-ray spectrum ? - P. Pradhan (MIT, USA), B. Paul, E. Bozzo (Univ. of Geneva), C. Maitra (Germany), B. C. Paul, *Mon. Notice Royal Astronomical Society* (MNRAS) 502, 1163-1190 (2021)

19. Compacy Objects in f(R,T) gravity in Finch-Skea geometry - S. Dey, A. Chanda, B. C. Paul, Euro. Phys. J Plus, 136, 228 (2021)

20. Bouncing scenario with causal cosmology - P S Debnath and B C Paul, Astrophysics and Space Science, 366, 32 (2021)

21. Gravitational collapse of Anisotropic star - S. Das, B. C. Paul, R. Sharma, Indian Journal of Physics 95 (12), 2873-2883 (2021)

22. Existence of Traversable Wormholes with Modified Gravity and Non-linear Equation of State – B. C. Paul, *Class. Quantum Grav.* 38 145022 (2021).

23. Gravitational collapse of Anisotropic star - S. Das, B. C. Paul, R. Sharma, Indian Journal of Physics 95 (12), 2873-2883 (2021)

Department of Physics, DDU Gorakhpur University, Gorakhpur During April 1, 2021 to March 31, 2022

Coordinator:
Dr. Shantanu Rastogi

Area of research

- Infrared observations of stars
- Circumstellar and Interstellar Medium
- Molecules of Astrophysical importance
- Star clusters
- Atmospheric aerosols
- **Trace gases in planetary atmospheres** etc.

The ICARD members at Gorakhpur and surrounding areas including Varanasi and Lucknow mainly work in the areas – **Infrared observations of stars, Circumstellar and Interstellar Medium, Molecules of Astrophysical importance, Star clusters, Atmospheric aerosols, Trace gases in planetary atmospheres** etc.

Amit Pathak, BHU and Shantanu Rastogi, DDUGU have studied various aspects of astrophysical infrared emission features and their possible carrier polycyclic aromatic hydrocarbon (PAH) molecules. Study of Globular Clusters is being carried out in collaboration with ARIES, Nainital by Apara Tripathi, DDUGU. Theoretical studies on chemistry of formation of pre-biotic molecules in interstellar medium are being done by Alka Mishra, LU. Analysis of Astrosat observations by Sanjay Pandey, LBS Gonda. Continuous monitoring of atmospheric aerosols at Gorakhpur and study of satellite data on atmospheric trace gases is being carried out by Prabhunath Prasad and Shantanu Rastogi, DDUGU.

Lectures

1. Special Lecture (online) on *Time & Frequency Standards* by Ashish Agarwal, NPL, Delhi, on the occasion of World Standards Day (14 Oct) on 20-Oct-2021 (jointly in collaboration with Institution of Engineers, Gorakhpur Chapter).
2. Special Lecture (online) on *Observations from Space* by Prakash Chauhan, Director, IIRS (ISRO), Dehradun, on 8-Dec-2021.

Publications using ICARD facilities

1. ab-Initio and DFT study of HCN: Role of temperature for the formation of HCN molecule in the interstellar medium; M. Yadav, Shivani, A. Ahamad, K. K. Singh, R. Singh, **A. Misra**, P. Tandon; J. Mol. Struc., 1248, 2022.
2. Formation of aminomethanol in ammonia-water interstellar ice; K. K. Singh, P. Tandon, R. Kumar, **A. Misra**, Shivani, M. Yadav, A. Ahmad, M. K. Chaudhary; MNRAS, 506 (2), 2059 – 2065, 2021.
3. Theoretical study of infrared spectra of interstellar PAH molecules with N, NH, and NH2 incorporation; A, Vats, **A. Pathak**, T, Onaka, M. Buragohain, I. Sakon, I. Endo; Publications of the Astronomical Society of Japan, 74(1), 161–174, 2022.
4. Evidence for Coronal Temperature Variation in Seyfert 2 ESO 103–035 Using NuSTAR Observations; S. Barua, V. Jithesh, R. Misra, G. C. Dewangan, R. Sarma, **A. Pathak**, B. J. Medhi; ApJ, 921, 46, 2021.
5. Chemical Complexity of Phosphorous-bearing Species in Various Regions of the Interstellar Medium; M. Sil, S. Srivastav, B. Bhat, S. K. Mondal, P. Gorai, R. Ghosh, T. Shimonishi, S. K. Chakrabarti, B. Sivaraman, **A. Pathak**, N. Nakatani, K. Furuya, A. Das; The Astronomical Journal, 162(3), 39, 2021.
6. Conformational and vibrational spectroscopic investigation of N-

n-butyl, S-2-nitro-1-(p-tolyl) ethyl dithiocarbamate - a bio-relevant sulfur molecule; T. Yadav, G. Brahmachari, I. Karmakar, P. Yadav, A. K. Prasad, **A. Pathak**, A. Agarwal, R. Kumar, V. Mukherjee, G. N. Pandey, R. R. F. Bento, N. P. Yadav; Journal of Molecular Structure, 1238, 130450, 2021.

7. Accretion disc sizes from continuum reverberation mapping of AGN selected from the ZTF survey; V. K. Jha, R. Joshi, H. Chand, X. Wu, L. C. Ho, **S. Rastogi**, Q. Ma; MNRAS, 511(2), 3005 – 16, 2022.

8. A comparative study of the physical properties for a representative sample of Narrow and Broad-line Seyfert galaxies; V. K. Jha, H. Chand, V. Ojha, A. Omar, **S. Rastogi**; MNRAS, 510(3), 4379 – 93, 2022.

Outreach programmes

1. Shantanu Rastogi delivered online lecture on *Measuring the Universe* on 10-Dec-2021 organized by the Astronomy and Astrophysics Club (VINN), Central Univ. of T.N.

2. Science day film show on *Cosmic Collisions* was organized at DDUGU for M.Sc. students on 28-Feb-2022.

Gurukula Kangri (Deemed to be University), Haridwar April 1, 2021-March 31, 2022

Coordinator:
Dr. Hemwati Nandan

Areas of research

- GR and Alternative Theory of Gravity
- Black Hole Physics
- Dark Energy and Dark Matter
- Gravitational Lensing and Shadow
- Non-Linear Dynamics and Chaos

Research work done

The members associated with ICARD, Haridwar have worked on different issues related to the areas as mentioned in the areas of research during the assessment period. We have worked on the optical properties (shadow and gravitational lensing) and thermodynamic properties of some interesting spacetimes in general relativity (GR) and in alternative theories of gravity. In particular, we have studied the motion of photons in ADS geometry to observe the effect of different charges on the path of the light along with the shadows and the relation for distance of closest approach with the magnetic charges, the gauge coupling constant and NUT charge. We have also investigated the shadow and deflection angle of charged rotating black hole surrounded by perfect fluid dark matter and Rotating charged black hole in 4D Einstein-Gauss-Bonnet gravity. The horizon, energy emission from a given black hole spacetime has been investigated. The study of bending angle of light in a solution representing a fluid with a constant equation of state which can for example describe an effective warm dark matter fluid around a black hole was performed. We had analyzed the deflection angle produced by the black hole in view of various black hole parameters. An exact solution for bending angle was also determined for a particular value of the equation of state parameter. The study of gravitational lensing and black hole shadows around a dual-charged stringy black hole spacetime derived in dilaton-Maxwell gravity. The variation of deflection angle with the impact parameter for different values of black hole parameters was studied. The shadow of this black hole spacetime was investigated also the radius of the shadow was studied in detail. We had also contributed to the study of gravitational lensing around a rotating Bañados–Teitelboim–Zanelli (BTZ) black hole in (2 + 1)-dimensional gravity in which a detailed discussion for orbits for massless test particles around this black hole spacetime to understand the nature of cosmological constant in lower dimensions was presented. The effect of the cosmological constant on the photon orbit in view of other critical black hole parameters had studied. The bending angle of light was also investigated for different values of cosmological constant for direct and retrograde motion of test particles. In another paper entitled "Optical and thermodynamic properties of a rotating dyonic black hole spacetime in N=2, U $(1)^2$ gauged supergravity" a detailed study of gravitational shadows and thermodynamics was performed. The null geodesics and the distance of the closest approach for the photon were also studied. Further, the investigation of various thermodynamic properties for BH with dyonic charges is also studied. We have obtained various thermodynamic parameters at the horizon.

More recently, we have also performed the stability analysis of circular geodesics along with quasinormal modes for scalar field perturbation in the vicinity of a dual stringy black hole and non-commutative geometry inspired Schwarzschild black hole. Stability analysis of circular orbits around a charged BTZ black hole spacetime in a nonlinear electrodynamics model is studied. Also, stability analysis of circular orbits around Kerr black hole and traversable wormhole with massless conformally coupled scalar field are investigated via Lyapunov stability criteria.

Workshops/Schools organized

An International Conference on Cosmology & Gravity (CosmoGrav22) was successfully organized during 22-23 March 2022. The conference was inaugurated by Prof. Ajit Khembhavi. The following speakers has delivered the invited lectures during the conference:

(I) Prof. Emilio Tejeda (Mexico): Choked accretion: from Bondi accretion to bipolar outflows.

(ii) Dr. Umananda Dev Goswami (India): Gravitational wave physics in the light of ATGs.

(iii) Prof. Phillipe Jetzer (Switzerland): Tests of GR with LISA and ACES.

(iv) Dr. Sandipan Sen Gupta (India): Extra dimension(s) of vanishing proper length: A non-Einsteinian phase in gravity and the implications for the 'dark matter' problem.

(v) Dr. Farruh Atamurotov (Uzbekistan): Black hole shadows and gravitational lensing.

(vi) Prof. Alfredo Herrera Aguilar (Mexico): Black Hole rotation curves for astrophysical systems.

(vii) DR. Amare Abebe (South-Africa): Linearized perturbations of a darkfluid-dominated universe.

(viii) Prof. Rituparno Goswami (South-Africa): Tidal forces and Gravitational waves.

(ix) Prof. Eva Hackmann (Germany): Shapiro and Frame dragging delays in pulsar timing.'

Around two hundred participants were present in this conference and twenty-five contributory papers were also presented by the young participants (mainly the Ph.D. students working in different universities in India and abroad). Some of the glimpses of this conference are mentioned in few photographs below.

List of publications using ICARD facilities

1. Farruh Atamurotov, Uma Papnoi, Kimet Jusufi, Shadow and deflection angle of charged rotating black hole surrounded by perfect fluid dark matter. Class. Quantum Grav. 39 (2022) 025014 (20pp).

2. Uma Papnoi, Farruh Atamurotov, Rotating charged black hole in 4D Einstein–Gauss–Bonnet gravity: Photon motion and its shadow. Physics of Dark Universe 35 (2022), 100916.

3. Prateek Sharma, Hemwati Nandan, Uma Papnoi, Arindam Kumar Chatterjee, Optical and Thermodynamic properties of a rotating dyonic black hole spacetime in N = 2 U(1)2 gauged supergravity. Eur. Phys. J. C (2021) 81:429.

4. Shubham Kala, Hemwati Nandan, Prateek Sharma, Maye Elmardi, Geodesic and Bending of Light Around a BTZ Black Hole Surrounded by Quintessential Matter Modern Physics Letters A, Vol. 36, No. 31 (2021) 2150224.

5. Shobhit Giri, Hemwati Nandan, Lokesh Kumar Joshi and Sunil D. Maharaj, Stability analysis of circular orbits around a traversable wormhole with massless conformally coupled scalar field, The European Physical Journal C 82:298, (2022).

6. Pradeep Singh, Hemwati Nandan, Lokesh Kumar Joshi, Nidhi Handa and Shobhit Giri, Stability of circular geodesics in equatorial plane of Kerr spacetime, The European Physical Journal Plus 137:263, (2022).

7. Prateek Sharma, Hemwati Nandan, Gamal G. L. Nashed, Shobhit Giri and Amare Abebe, Geodesics of a Static Charged Black Hole Spacetime in f(R) Gravity Symmetry, 14, 309; (2022).

8. Shobhit Giri, Hemwati Nandan, Lokesh Kumar Joshi and Sunil D. Maharaj, Geodesic stability and quasinormal modes of non-commutative Schwarzschild black hole employing Lyapunov exponent The European Physical Journal Plus 137:181, (2022).

9. Shobhit Giri, Hemwati Nandan, Lokesh Kumar Joshi and Sunil D. Maharaj, Stability analysis of circular orbits around a charged BTZ black hole spacetime in a nonlinear electrodynamics model via Lyapunov exponents, Modern Physics Letters A 36, 2150220, (2021).

10. Shobhit Giri and Hemwati Nandan, Stability analysis of geodesics and quasinormal modes of a dual stringy black hole via Lyapunov exponents, General Relativity and Gravitation 53 (8), (2021).

Outreach programs (including public lectures/sky watch) arranged by ICARD, etc.

Sky Watch Activity was organized by ICARD, GK (DU) Haridwar during 24-25 February, 2022 in collaboration with ARIES, Nainital. Around 1500 students of our campus and nearby schools have participated in this programme to watch sunspots and night sky objects. Dr. Virendra Yadav, ARIES, Nainital has also presented an interesting talk during this event. Few glimpses of this programme are presented below.

Awards

Dr. Hemwati Nandan (Coordinator, ICARD) was honored with best teacher award by Hon'ble Vice-Chancellor Gurukula Kangri (Deemed to be University) Haridwar on 26 January, 2022.

Department of Physics, Cochin University of Science and Technology: Activities from 01 April 2021 till 31 March 2022

Coordinator:
Prof. Titus K Mathew

Area of Research: Gravity, Cosmology and Astrophysics

We have two faculty members, Prof. Titus K Mathew and Dr. Charles Jose, who are leading the research and related ICARD activities in ICARD, Kochi. At present 7 research scholars are working in these area for their Ph.D. We have one on-going project, with Dr. Charles Jose funded by DST, Govt. Of India.

Talk

Talk by Prof. Titus K Mathew on March 10, 2022: "Thanu Padmanabhan and Atoms of space-time" – This talk highlights the contribution of Prof. Padmanabhan on Gravity. The talk was attended by a spectrum of undergraduate, graduate, and research students from the University.

Talk by Dr. Karthik Rajeev, IIT, Mumbai on April 12, 2022: "Quantum tunneling in real and imaginary time: applications and recent developments". Quantum tunnelling process can be semi-classically described in terms of trajectories in imaginary time. Although this result is very well known, the precise sense in which the concept of 'imaginary time' appears more rigorously in quantum mechanics is less discussed. In this talk, I will show a simple example in which, starting from a path integral formalism in real time, one can naturally arrive at the 'imaginary time' based picture of tunneling in a rather mathematically rigorous manner.

Publications using ICARD Facilities

1. Jerin Mohan N D and Titus K Mathew, 'On the feasibility of truncated Israel-Stewart model in the context of late acceleration', Class. Quant. Grav. 38 (2021) 14 145016.

Abstract: A dissipative model of the Universe based on the causal relativistic truncated Israel-Stewart theory is analysed in the context of recent accelerated expansion of the Universe. The bulk viscosity and relaxation time are taken as $\xi=\alpha\rho s$ and $\tau=\alpha\otimes\gamma(2-\gamma)\rho s-1$ respectively. For $s=1/2$, we found an analytical solution for the Hubble parameter of the model. We have estimated the model parameters by treating $\gamma=1$ and γ as a free parameter using the latest cosmological data.

The model predicts a prior decelerated phase and an end de Sitter phase as in the standard ΛCDM model. The dynamical system analysis shows that the prior decelerated epoch is an unstable equilibrium, while the far future de Sitter epoch is stable. The age of the Universe obtained around 13.66 Gyr, which is close to the recent observations. The second law of thermodynamics is found to be satisfied throughout the evolution in this model. The feasibility of the model has been checked by contrasting with models based on the full Israel-Stewart and the Eckart viscous theories. The truncated viscous model appears more compatible with astronomical observations than the Eckart and full causal viscous models.

2. Sarath N and Titus K Mathew, 'Decaying vacuum and evolution from early inflation to late acceleration', Mod. Phys. Lett. B 36 (2021) 23, 2150160.

   Abstrac: Decaying vacuum models are a class of models that incorporate the vacuum energy density as a time-evolving entity that has the potential to explain the entire evolutionary history of the universe in a single framework. A general solution to the Friedmann equation can be obtained by considering vacuum energy density as a function of the Hubble parameter. We have obtained the asymptotic solution by choosing the appropriate equation of state for matter and radiation. Finite boundaries in the early and late de Sitter epoch could be defined by considering the evolution of primordial perturbation wavelength. An epoch invariant number *Nc* determines the number of perturbation modes that cross the Hubble radii during each epoch has been obtained.

3. Sarath N and Titus K Mathew, 'Running vacuu model versur LambdaCDM – a bayesian analysis', Mon. Not. Roy. Astron. Soc. 510 (2022) 4, 5553.

   Abstract: We study the running vacuum model in which the vaccum energy density depends on square of Hubble parameter in comparison with the ΛCDM model. In this work, the Bayesian inference method is employed to test against the standard ΛCDM model to appraise the relative significance of our model, using the combined data sets, Pantheon+CMB+BAO and Pantheon+CMB+BAO+Hubble data. The model parameters and the corresponding errors are estimated from the marginal likelihood function of the model parameters. Marginalizing over all model parameters with suitable prior, we have obtained the Bayes factor as the ratio of Bayesian evidence of our model and the ΛCDM model. The analysis based on Jeffrey's scale of bayesian inference shows that the evidence of our model against the ΛCDM model is weak for both data combinations. Even though the running vacuum model gives a good account of the evolution of the universe, it is not superior to the ΛCDM model.

Department of Physics, University of Calicut during April 1, 2021 – March 2022

Coordinator:
Prof. C. D. Ravikumar

Area of research

- Galaxy formation and evolution, Active Galactic Nuclei.

Seminars conducted.

1. Online seminar on Simultaneous UV/Optical, X-ray spectral analysis of Fermi bright Blazar by Aminabi T on May 19, 2021
2. Online seminar on CIR scaling relations for early-type galaxies hosting nuclear star clusters by Sruthi K on Jun 9, 2021.
3. Online seminar on Infra-red central intensity ratio study in early-type galaxies by Baheeja. C on July 7, 2021.
4. Online seminar on Study of central intensity ratio in nearby seyfert galaxies by Vinod K T on July 14, 2021
5. Online seminar on Signature of jet MHD turbulence in blazar spectra by Habeeb Rahman. C on Aug 4, 2021.
6. Online seminar on Analysis and Interpretation of spectral features or blazar by Sitha K Jagan on October 20, 2021

Publications using ICARD facilities

1. 'Convex X-ray spectra of PKS 2155-304 and constraints on the minimum electron energy', 2021, Jagan, Sitha K. ; Sahayanathan, S. ; Rieger, Frank M. ; Ravikumar, C. D., Monthly Notices of the Royal Astronomical Society, Volume 506, 3996-4006 (2021), doi:10.1093/mnras/stab1993.

School of Physical Sciences, S.R.T.M. University, Nanded April 1, 2021 – March 2022

Coordinator:
Madhav K. Patil

Areas of Research

- AGN feedback in galaxy clusters
- Optical/X-ray variability of AGN
- X-ray astronomy
- XRB population in galaxies
- Multi-phase ISM in early- type galaxies.

The School of Physical Sciences has only one faculty member working in the field of Astronomy and Astrophysics. However, the ICARD activities are supported by 08 research scholars working in the School and also by 20 M Sc Final Year students with Astrophysics specialization.

- **Conference / Seminar**

1. K. Wani, H. Gaur & **M. K. Patil**; X-ray studies of Blazar 1ES 1959+650 using SWIFT & XMM-Newton Satellite, in the 40th Astronomical Society of India Meeting during 25-29, 2022 organized by IIT Roorkee and ARIES, Nainital (in online mode)
2. Rupesh N. Ghodpage, Alok Taori, O. B. Gurav, P. T. Patil and **M. K. Patil**; Covid-19 pandemic impact on ground based airglow observation over kolhapur, in the National Space Science Symposium (NSSS-2022) during Jan 31 – Feb 4, 2022 by IISER, Kolkatta.

Publications using ICARD Facilities

1. N. D. Vagshette, S Naik, N Kumari, **M K Patil**; *Imaging and photometric studies of NGC 1316 (Fornax A) using Astrosat/UVIT*; JAA; 42 (2), 1-8, 2021
2. A Kyadampure, N. D. Vagshette, **& M. K. Patil;** *X-ray cavities in the G50 bright group- centered galaxy NGC 5846*; SAA, 17-24,2021

Ph Ds awarded

1. **Dr. Bhagorao Tukaram Tate** received Ph D. in Physics from S.R.T.M. University, Nanded in April 2022 for the thesis entitled ***"Multiphase Interstellar Medium and Star Formation History in Early-type galaxies"***

ICARD BENEFICIARIES

Facilities at ICARD-SRTMU were availed by our regular students as well as visitors from nearby region. List of the beneficiaries are:

1. Dr N D Vagshette, Asst. Professor, M U Mahavidyalaya, Udgir
2. Dr B T Tate, Balbhim Mahavidyalaya, Beed
3. Mr. A. T. Kyadampure, Sanjivani Mahavidyalaya, Chapoli, Dist. Latur
4. B. Sc. Physics students and faculty from Gramin Mahavidyalaya, Kotgyal
5. Members from Parbhani Astronomical Society, Parbhani
6. Post graduate students, teaching and non-teaching staff from campus schools
7. Students and Teachers from Swiss Academy English School, Parbhani
8. BA/B Com students and teachers from people's College, Nanded

Outreach programs (including public lectures/sky watch) arranged by ICARD

Due to the prevailing COVID situation the ICARD at S.R.T.M. University, Nanded could not conduct formal activities like workshops, seminars, conferences, etc in offline mode. However, has conducted various events, lectures in online mode and faculty at the School has delivered number of science outreach talks on various occasions. The details of such activities are listed below:

i. Sky-Watch using 16" ACF MEADE Telescope on the occasion of Science Day celebration (28th Feb 2022)

ii. Popular talk followed by Sky-Watch for the BA / B Com students from People's College, Nanded on 16th March 2022. More than 100 students along with teachers attended this event.

iii. Delivered a popular talk on "***Opportunities in Physics***" in the One Day State Level Webinar organized by Baliram Patil Arts, Commerce and Science College, Kinwat as a part of the celebration of "***Azadi Ka Amrut Mahotsav***" on 21st January 2022

iv. Delivered a scientific talk on "***Astronomical Telescopes: Construction and working***" in the Scientist Interaction Programme jointly organized by Vasantrao Naik Marathwada Agricultural University, Parbhani and Parbhani Astronomical Society in the context of the establishment of Science center on 12th December 2021

v. Delivered a popular talk on "***Science Models in the proposed Science Center at VNMA University, Parbhani***" in the Scientist Interaction Programme jointly organized by Vasantrao Naik Marathwada Agricultural University, parbhani and Parbhani Astronomical Society on 11th December 2021

vi. Delivered a talk on "***Astronomical Observations***" followed by the Sky-Watch for the students and staff of Swiss Academy English School, Parbhani on 17th Nov 2021.

vii. Delivered a popular talk on "***Opportunities after M Sc Physics***" in the one day program organized by the Netaji Subhash Chandra Bose College, Nanded on 18th October 2021

viii. Delivered the convocation address on "***New Education Policy 2020 and Challenges before Higher Education***" of Bahirji Smarak Mahavidyalaya, Basmathnagar on 16th October 2021

ix. Delivered a science popularization talk in the One Day National Webinar on "***Gravitational Waves: New Window to Explore the Unseen Universe***" on 6th

October 2021 organized by Department of Physics & IQAC, Balbhim Arts, Science and Commerce College, Beed

x. Delivered a talk on "***New Education Policy 2020 and Revision of Physics Curriculum***" in the National Level Workshop jointly organized by S.R.T.M. University, Nanded and Mahatma Gandhi Mahavidyalaya, Ahmedpur on 24th September 2021

Delivered a talk on "***Gravitational Waves: Quest to explore Unseen Universe***" in the National E-conference on Advances in Mathematics and Physics organized by Shri Datta Arts, Commerce & Science College, Hadgaon, Dist. Nanded on May 12, 2021

Department of Physics, Tezpur University, Napaam during April 1, 2021 – March 2022

Coordinator:
Dr. Rupjyoti Gogoi

Areas of research:

Interstellar Dust, Active Galactic Nuclei, Morphological Study of Galaxies, X-ray Astronomy, Solar Astronomy.

One/two paragraphs about the research work done in ICARD:

Faculty members and PhD students of Department of Physics, Tezpur University are involved in collaborative research work with IUCAA faculty members through joint supervision. Two such PhD students obtained doctorate from Tezpur University during 2021-2022. They are:

1. Dr. Pranjupriya Goswami, thesis title, "Broadband Study of the Spectral and Temporal Behaviour of Blazars", awarded in 2021. (In collaboration with Prof. Ranjeev Misra)

2. Dr. Rukaiya Khatoon, "Multi-wavelength Temporal Study of Blazars", awarded in 2022. (In collaboration with Prof. Ranjeev Misra)

There are ongoing research work on Galaxy morphology, Active Galactic Nuclei, X-ray Astronomy and Solar Astronomy in active collaboration with IUCAA faculty members. Group members of Prof. Gazi Ameen Ahmed and Dr Rupjyoti Gogoi are involved in these collaborative research works.

List of any workshops/schools organised by ICARD:

- **North East Meet of Astronomers (NEMA):**

Department of Physics, Tezpur University, in association with IUCAA, Pune initiated a series of meetings in 2015 to promote interaction and collaborations among Astronomers of North East India with a name "North East Meet of Astronomers (NEMA)". The idea of such meetings is to bring together young researchers including faculty members, research scholars and advance level M.Sc. students on a single platform to share their current and future research ideas. The seventh edition of NEMA was organised by Department of Physics, Rajiv Gandhi University during January 2022. ICARD, Tezpur University helped them in preparing the proposal and in conducting the event. The meeting was in online mode because of the pandemic situation. There were thirty talks in the meeting, out of which two were special talks by Prof. Ajit K Kembhavi and Prof. Somak Raychaudhury. Faculty members and students from different institutions of North East participated actively in the meeting. The meeting concluded with a lively interactive session conducted by Prof. Ranjeev Misra.

Publications by using ICARD facilities

Members of ICARD, Tezpur University have published the following journal and conference papers as collaborative efforts with IUCAA faculty members:

1. "Flux Distribution Study of Mkn 421 with SPOL, RXTE and Fermi-LAT Telescopes", Rukaiya Khatoon, Zahir Shah, Raj Prince, Ranjeev Misra, Rupjyoti Gogoi, Selected Progresses in Modern Physics, Springer Proceedings in Physics, vol 265. Springer, Singapore (2021).

2. "Understanding the X-ray spectral curvature of Mkn⊗421 using broad-band *AstroSat* observations", Jyotishree Hota, Zahir Shah, Rukaiya Khatoon, Ranjeev Misra, Ananta C Pradhan, Rupjyoti Gogoi, Monthly Notices of the Royal Astronomical Society, Volume 508, Issue 4, page 5921 (2021)

3. "The long-term X-ray flux distribution of Cygnus X-1 using RXTE-ASM and MAXI observations", Kabita Deka, Zahir Shah, Ranjeev Misra, Gazi Ameen Ahmed, Journal of High Energy Astrophysics, Volume 31, page 23 (2021)

4. "Distribution of X-Ray Flux: RXTE-PCA Observation of Cygnus X-1", Kabita Deka, Zahir Shah, Ranjeev Misra, Gazi Ameen Ahmed, Selected Progresses in Modern Physics, Springer Proceedings in Physics, vol 265. Springer, Singapore (2021).

"X-ray emission study of extreme blazars using AstroSat", Pranjupriya Goswami, Atreyee Sinha, Nijil Mankuzhiyil, Ranjeev Misra, Zahoor Malik, Sunder Sahayanathan, Sunil Chandra and Rupjyoti Gogoi, Proceedings of Science, 37th International Cosmic Ray Conference, 12-23 July 2021.

School of Studies in Physics and Astrophysics, Pt. Ravishankar Shukla University, Raipur during April 1, 2021 – March 2022

Coordinator:
N. K. Chakradhari

Areas of research

Supernovae, Galaxies and Variable stars etc.

Research work

UV-optical photometric and spectroscopic study of supernovae is being carried out by N.K. Chakradhari and Shritika Tiwari (Thesis work) in collaboration with G.C. Anupama, D.K. Sahu (IIA, Bengaluru) and Kuntal Misra (ARIES, Nainital).

Study of Chemically Peculiar stars/ Variable stars is being carried out in collaboration with S. Joshi (ARIES, Nainital).

Study of central region of lenticular galaxies is being carried out by S.K. Pandey, Mahendra Verma (Thesis work) and S. Barwey (IIA Bengaluru).

N.K. Chakradhari is involved in the co-supervision of (i) Massive O-type and WR stars, Thesis work of Ms. Bharti Arora with J. C. Pandey, ARIES, Nainital (ii) Study of GRBs, Thesis work of Ankur Ghosh with Amitesh Omar and Kuntal Misra, ARIES, Nainital.

Publications by using ICARD facilities

1. Study of chemically peculiar stars - I. High-resolution spectroscopy and K2 photometry of Am stars in the region of M44, Joshi Santosh et al.; Chakradhari N. K. (co-author), 2022, MNRAS,510, 5854.
2. Quest for the Upcoming Periastron Passage of an Episodic Dust Maker and Particle-accelerating Colliding-wind Binary: WR 125, Arora Bharti; Pandey J. C.; De Becker Michaël; Pandey S. B.; Chakradhari Nand K.; Sharma Saurabh; Kumar Brijesh, 2021, AJ, 162, 257.
3. PSN J0910+5003 : A type Ia Supernova explosion similar to Super Chandrasekhar event, Shrutika Tiwari, N. K. Chakradhari, D.K. Sahu, G. C. Anupama presented at 40th annual Meeting of the Astronomical Society of India (ASI 2022) at IIT, Roorkee 25-29 March 2022.

Outreach programmes, including public lectures/sky watch etc.

Invited talks/public lectures (1) "The story of stars", National Science Day Celebration at Govt College Kurud, 28 February 2022 (2) "Space Science and Technology for a sustainable future", National Science Day Celebration at Govt. College Dharsiva, 26 February 2022 (3) "India in Space Science", National Science Day Celebration at Govt. Gundadhur College Kondagaon, 05 February 2022 (4) "Opportunities and Challenges in Physics" at Govt College Rajim, 21 January 2022 (5) "Sun, Season and Sky" at Kalinga University Raipur on 11 December 2021 (6) "Astrophysics – The Wonders of Galaxies" at Vinayakrao Patil Mahavidyalaya, Vaijapur, Aurangabad, 14 September 2021 (7) "Motion of the Sun", Training workshop on Zero Shadow Day, Organized by Chhattisgarh Vigyan Sabha, 15 May 2021

Sky watching programmes were organized (1) at SoS in Physics & Astrophysics, Pt R.S. University Raipur (Azadi ka Amrit Mahotsav) on 7-8 December 2021 (2) at Savitri Bai Phule Educational Academy Saddu, Raipur on 26 December 2021 (3) at Korba on 11 December 2021.

Department of Physics, University of Kashmir, Srinagar during April 1, 2021 – March 2022

Coordinator:
Manzoor A. Malik

Areas of Research

Theoretical Astrophysics, Cosmology, X-ray Astronomy, Galaxy Clusters

Research work

The department has three permanent faculty members (two Professors and one Associate Professor) in the field of Astronomy and Astrophysics. As on date, the department host 12 research students in Astronomy and Astrophysics alone. Further, there are four ongoing research projects in the area of Astronomy and Astrophysics funded by SERB-DST, ISRO RESPOND etc.

Workshop

A two day Introductory Workshop on Astronomy and Astrophysics was held in the department in hybrid mode on 18th and 19th of December, 2021. The coordinators of the workshop were Naseer Iqbal (local) and Ranjeev Misra (IUCAA). The workshop was attended by around hundred students and young faculty from local universities. While the workshop was conducted offline, some of the resource persons delivered their talks online; these include Somak Raychaudhary (Director), Kanak Saha, Ranjan Gupta, Sanjit Mitra, Durgesh Tripathi all from IUCAA. Some of the local resource persons included me, Naseer Iqbal, Waseem Bari, Bari Maqbool and Zahir Shah. At the end, Ranjeev Misra gave his impressions about the workshop and conducted an online interaction with the participants.

Since the workshop was conducted in a period during which COVID was still close to severe, all COVID protocols were followed. Happy to report that none of the participants or resource persons contracted COVID during or immediately after the workshop. Another workshop on Python and Astronomical Data Analysis is scheduled to be held in June 2022.

Newman College, Thodupuzha, Kerala during from April 1, 2021 to March 31, 2022.

ICARD NEWMAN COLLEGE

Areas of research

Radio Astronomy, X-ray Astronomy and Machine Learning.

Research Work

There are four research scholars in the Department of Physics, Newman College, Thodupuzha, Kerala who are using ICARD facilities for doing research in the fields of Radio Astronomy, X-ray Astronomy and Machine Learning.

Prof. Thanu Padmanabhan Memorial Talk

A memorial Talk to pay tributes to the late Prof. T. Padmanabhan was conducted on his birthday, the 10th of March, under the auspices of the ICARD. Paddy's student and Post-doctoral research fellow of IIT, Powai, Dr. Karthik Rajeev gave a web talk on the "Academic Legacy of Thanu Padmanabhan" during the occasion. The programme attendance was in a hybrid mode whereby the students of the college attended the programme which was screened at the college and the other participants joined online. The programme commenced at 11.30 am with a welcome speech by Dr. Aloysius Sabu N. (Head of the Dept.) followed by Dr. Joe Jacob, former HOD and Co-ordinator of ICARD, sharing fond memories of the visit of Prof. Thanu Padmanabhan to the college. Programme coordinator Sri. Noble C Kurian delivered the vote of thanks. There were more than 100 participants including researchers and students from the region.

Outreach programmes:

(a) Lunar Day Celebration

Department of Physics conducted the Lunar Day Celebration in association with ICARD on 24th July 2021 at 10.00 am through The Google meet platform. The programme started with a welcome speech by Dr. Aloysius Sabu N. (Head of the Dept). Dr. Joe Jacob, Co-ordinator of ICARD inaugurated the programme. Seminars on the topics of Apollo Missions - Failure and success, Voyage to Moon, Chandrayan and Upcoming Lunar Missions were presented by the students.

Dr. Beena Mary John, Asst. Prof.Dept. of Physics proposed the vote of thanks

Science popularisation Documentary

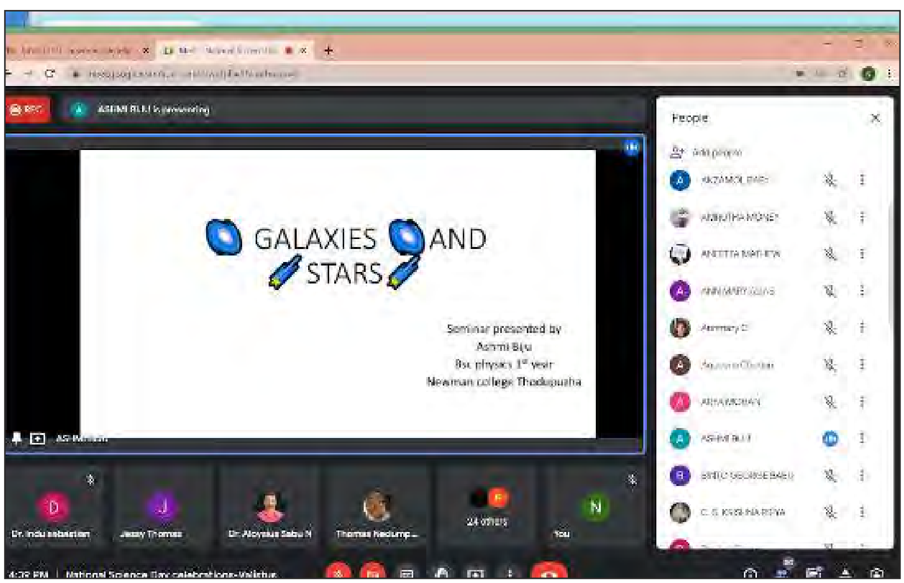
As a part of the lunar day celebrations under the auspices of the ICARD, A science popularisation documentary was prepared and exhibited at the P N UP School Kanjiramukku , Thrissur Dt, Kerala on July 21 by Ms.Nimmy Tresa Thomas of Newman College. 300 students participated in the programme.

(b) Ozone Day Celebration

The Department of Physics commemorated the International Day for the preservation of Ozone Layer with the theme " Ozone for Life " in association with ICARD on 21st September 2021 at 2:30 pm. Dr. Beena Mary John, Asst. Professor in Physics, Newman College Thodupuzha welcomed the gathering and Dr. Aloysius Sabu N, Head of the department delivered the Presidential Address. The celebrations started with an Ozone Day message on the theme ' Ozone for Life ' by Dr. Smitha Thankachan Assistant Professor, MA College Kothamangalam. The talk which was arranged in the Google meet platform was attended by more than 100 participants from the region. Ms. Nandana. S. Pradeep led the oath-taking by the students to preserve the environment, conducted after the talk. Quiz and poster making competitions, highlighting the need of Ozone Layer protection were also conducted. 67 students participated in the online quiz conducted in the online platform. 53 students participated in the poster presentation contest and the posters were exhibited as a video presentation in the Google platform. The winners in the competitions were awarded mementos and certificates .Ms. Jeteena Joseph delivered the vote of thanks.

(c) National Science Day Celebration:

Seminar presentation competition: A contest for the students to present the recent advancements in Physics as short seminars was conducted on March 5, 2022, in association with ICARD, as a part of the National Science Day celebrations. Prof. Rageena Joseph, Prof.Jessy Thomas, (former faculty, Newman College and Mr. Krishnaprasad (CSIR JRF) were the judges of the program. Twelve students participated in the competition the winners were awarded cash prizes, mementos and certificates.



PUBLICATIONS BY IUCAA MEMBERS

1. R. Abbott, ... **S. Abraham, D. Agarwal, D. Bankar, R. S. Bankar, A. V. Bhandari, S. Biswas, S. Bose, K. Chakravarti, S. Choudhary, M. Deenadayalan, S. Dhurandhar, S. Doravari, S. G. Gaonkar, S. P. Jadhav, S. Kandhasamy, A. Mhaske, S. Mitra, A. More, K. S. Phukon, S. Ponrathnam, Santosh Roy, T. R. Saravanan, V. Savant, H. L. Sawant, K. Soni, T. Souradeep, S. Sudhagar, M. P. Thirugnanasambandam**, et al (2021) *All-sky search in early O3 LIGO data for continuous gravitational-wave signals from unknown neutron stars in binary systems*, PhRvD, **103**, 064017.

2. R. Abbott, ... **S. Abraham, D. Bankar, R. S. Bankar, A. V. Bhandari, S. S. Bose, K. Chakravarti, S. Choudhary, M. Deenadayalan, S. Dhurandhar, S. Doravari, S. G. Gaonkar, S. P. Jadhav, S. Kandhasamy, A. Mhaske, S. Mitra, K. S. Phukon, S. Ponrathnam, Santosh Roy, T. R. Saravanan, H. L. Sawant, V. Savant, T. Souradeep, S. Sudhagar, M. P. Thirugnanasambandam**, et al. (2021) *Tests of general relativity with binary black holes from the second LIGO-Virgo gravitational-wave transient catalog*, PhRvD, **103**, 122002.

3. R. Abbott, ... **S. Abraham, D. Agarwal, D. Bankar, R. S. Bankar, A. V. Bhandari, S. Biswas, S. Bose, K. Chakravarti, S. Choudhary, M. Deenadayalan, S. Dhurandhar, S. Doravari, S. G. Gaonkar, S. P. Jadhav, S. Kandhasamy, A. Mhaske, S. Mitra, A. More, K. S. Phukon, S. Ponrathnam, Santosh Roy, T. R. Saravanan, V. Savant, H. L. Sawant, K. Soni, T. Souradeep, S. Sudhagar, M. P. Thirugnanasambandam**, et al. (2021) *Upper limits on the isotropic gravitational-wave background from Advanced LIGO and Advanced Virgo's third observing run*, PhRVD, **104**, 022004

4. R. Abbott, ... **S. Abraham, D. Agarwal, D. Bankar, R. S. Bankar, A. V. Bhandari, S. Biswas, S. Bose, K. Chakravarti, S. Choudhary, M. Deenadayalan, S. Dhurandhar, S. Doravari, S. G. Gaonkar, S. P. Jadhav, S. Kandhasamy, A. Mhaske, S. Mitra, A. More, K. S. Phukon, S. Ponrathnam, Santosh Roy, T. R. Saravanan, V. Savant, H. L. Sawant, K. Soni, T. Souradeep, S. Sudhagar, M. P. Thirugnanasambandam**, et al. (2021) *Search for anisotropic gravitational-wave backgrounds using data from Advanced LIGO and Advanced Virgo's first three observing runs*, PhRvD, **104**, 022005.

5. R. Abbott, ..., **S. Abraham, D. Agarwal, D. Bankar, R. S. Bankar, A. V. Bhandari, S. Biswas, S. Bose, K. Chakravarti, S. Choudhary, M. Deenadayalan, S. Dhurandhar, S. Doravari, S. G. Gaonkar, S. P. Jadhav, S. Kandhasamy, A. Mhaske, S. Mitra, A. More, K. S. Phukon, S. Ponrathnam, Santosh Roy, T. R. Saravanan, V. Savant, H. L. Sawant, K. Soni, T. Souradeep, S. Sudhagar, M. P. Thirugnanasambandam**, et al. (2021) *All-sky search for continuous gravitational waves from isolated neutron stars in the early O3 LIGO data*, PhRvD, **104**, 082004.

6. R. Abbott, ... **S. Abraham, D. Agarwal, D. Bankar, A. V. Bhandari, S. Biswas, S. Bose, K. Chakravarti, S. Choudhary, M. Deenadayalan, S. Dhurandhar, S. Doravari, A. Ganguly, S. G. Gaonkar, S. P. Jadhav, S. Kandhasamy, A. Mhaske, S. Mitra, A. More, S. Ponrathnam, Santosh Roy, T. R. Saravanan, V. Savant, H. L. Sawant, K. Soni, S. Sudhagar, M. P. Thirugnanasambandam**, et al. (2021) *Constraints on Cosmic Strings Using Data from the Third Advanced LIGO–Virgo Observing Run*, PhRvL, **126**, 241102.

7. R. Abbott, ... **S. Abraham, D. Agarwal, D. Bankar, R. S. Bankar, A. V. Bhandari, S. Biswas, S. Bose, K. Chakravarti, M. Deenadayalan, S. Dhurandhar, S. Doravari, S. G. Gaonkar, S. P. Jadhav, S. Kandhasamy, A. Mhaske, S. Mitra, A. More, K. S. Phukon, S. Ponrathnam, Santosh Roy, T. R. Saravanan, H. L. Sawant, V. Savant, K. Soni, T. Souradeep, S. Sudhagar, M. P. Thirugnanasambandam**, et al. (2021) *Observation of gravitational waves from two neutron star-black hole coalescences*, ApJL **915**, L5.

8. R. Abbott, ... **S. Abraham, D. Bankar, R. S. Bankar, A. V. Bhandari, S. S. Bose, K. Chakravarti, S. Choudhary, M. Deenadayalan, S. Dhurandhar, S. Doravari, S. G. Gaonkar, S. P. Jadhav, S. Kandhasamy, A. Mhaske, S. Mitra, K. S. Phukon, S. Ponrathnam, Santosh Roy, T. R. Saravanan, H. L. Sawant, V. Savant, T. Souradeep, S. Sudhagar, M. P. Thirugnanasambandam**, et al. (2021) *Search for Gravitational Waves Associated with Gamma-Ray Bursts Detected by Fermi and Swift during the LIGO–Virgo Run O3a*, ApJ, **915**, 86.

9. R. Abbott, ... **S. Abraham, D. Bankar, R. S. Bankar, A. V. Bhandari, S. S. Bose, K. Chakravarti, M. Deenadayalan, S. Dhurandhar, S. Doravari, S. G. Gaonkar, S. P. Jadhav, S. Kandhasamy, A. Mhaske, S. Mitra, K. S. Phukon, S. Ponrathnam, Santosh Roy, T. R. Saravanan, H. L. Sawant, V. Savant, T. Souradeep, S. Sudhagar, M. P. Thirugnanasambandam**, et al. (2021) *GWTC-2: Compact Binary Coalescences Observed by LIGO and Virgo during the First Half of the Third Observing Run*, PhRvX, **11**, 021053.

10. R. Abbott, ... **S. Abraham, D. Bankar, R. S. Bankar, A. V. Bhandari, S. Biswas, S. Bose, K. Chakravarti, M. Deenadayalan, S. Dhurandhar, S. Doravari, S. G. Gaonkar, S. P. Jadhav, S. Kandhasamy, A. Mhaske, S. Mitra, K. S. Phukon, S. Ponrathnam, Santosh Roy, T. R. Saravanan, V. Savant, H. L. Sawant, T. Souradeep, S. Sudhagar, M. P. Thirugnanasambandam**, et al. (2021) *Population Properties of Compact Objects from the Second LIGO–Virgo Gravitational-Wave Transient Catalog*, ApJ, **913**, L7

11. R. Abbott, ... **S. Abraham, D. Agarwal, D. Bankar, R. S. Bankar, A. V. Bhandari, S. Biswas, S. Bose, K. Chakravarti, S. Choudhary, M. Deenadayalan, S. Dhurandhar, S. Doravari, S. G. Gaonkar, S. P. Jadhav, S. Kandhasamy, A. Mhaske, S. Mitra, A. More, K. S. Phukon, S. Ponrathnam, Santosh Roy, T. R. Saravanan, V. Savant, H. L. Sawant, Soni, T. Souradeep, S. Sudhagar, M. P. Thirugnanasambandam**, et al. (2021) *Diving below the Spin-down Limit: Constraints on Gravitational Waves from the Energetic Young Pulsar PSR J0537-6910*, ApJL, **913**, L27.

12. R. Abbott, ... **S. Abraham, D. Agarwal, D. Bankar, R. S. Bankar, A. V. Bhandari, S. Biswas, S. Bose, K. Chakravarti, S. Choudhary, M. Deenadayalan, S. Dhurandhar, S. Doravari, S. G. Gaonkar, S. P. Jadhav, S. Kandhasamy, A. Mhaske, S. Mitra, A. More, K. S. Phukon, S. Ponrathnam, Santosh Roy, T. R. Saravanan, V. Savant, H. L. Sawant, K. Soni, T. Souradeep, S. Sudhagar, M. P. Thirugnanasambandam**, et al. (2021) *Searches for Continuous Gravitational Waves from Young Supernova Remnants in the Early Third Observing Run of Advanced LIGO and Virgo*, ApJ, **921**, 80.

13. R. Abbott, ... **S. Abraham, D. Agarwal, D. Bankar, R. S. Bankar, A. V. Bhandari, S. Biswas, S. Bose, K. Chakravarti, S. Choudhary, M. Deenadayalan, S. Dhurandhar, S. Doravari, S. G. Gaonkar, S. P. Jadhav, S. Kandhasamy, A. Mhaske, S. Mitra, A. More, K. S. Phukon, S. Ponrathnam, Santosh Roy, T. R. Saravanan, V. Savant, H. L. Sawant, K. Soni, T. Souradeep, S. Sudhagar, M. P. Thirugnanasambandam**, et al. (2021) *Constraints from LIGO O3 Data on Gravitational-wave Emission Due to R-modes in the Glitching Pulsar PSR J0537–6910*, ApJ, **922**, 71.

14. R. Abbott, ... **S. Abraham, D. Agarwal, D. Bankar, R. S. Bankar, A. V. Bhandari, S. Biswas, S. Bose, K. Chakravarti, S. Choudhary, M. Deenadayalan, S. Dhurandhar, S. Doravari, S. G. Gaonkar, S. P. Jadhav, S. Kandhasamy, A. Mhaske, S. Mitra, A. More, K. S. Phukon, S. Ponrathnam, Santosh Roy, T. R. Saravanan, V. Savant, H. L. Sawant, K. Soni, T. Souradeep, S. Sudhagar, M. P. Thirugnanasambandam**, et al. (2021) *Search for Lensing Signatures in the Gravitational-Wave Observations from the First Half of LIGO-Virgo's Third Observing Run*, ApJ, **923**, 14.

15. B. P. Abott, ..., S**. Abraham, A. Ain, S. Bose, K. Chakravarti, M. Deenadayalan, S. Dhurandhar, S. Doravari, S. G. Gaonkar, S. Kandhasamy. N. V. Keertana, S. Mitra, A. Parida, K. S. Phukon, S. Ponrathnam, J. Prasad, Javed Rana, T. Souradeep**, ..., et al. (KAGRA Collaboration, LIGO Scientific Collaboration and Virgo Collaboration) (2021) *Erratum: "A Gravitational-wave Measurement of the Hubble Constant Following the Second Observing Run of Advanced LIGO and Virgo" (2021, ApJ, 909, 218)*, ApJ, **923**, 279.

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BALANCE SHEET

The Bombay Public Trust Act, 1950

SCHEDULE - VIII
[Vide Rule 17 (1)]

Name of the Public Trust **Inter-University Centre for Astronomy and Astrophysics** Registration No. : **F-5366**

Balance Sheet As At : 31.03.2022 Dated : 27.01.1989

FUNDS & LIABILITIES	Rs.	Rs.	PROPERTY & ASSETS	Rs.	Rs.
Trusts Funds or Corpus :-			**Immovable Properties :- (At Cost)**		
Balance as per last Balance Sheet	2,10,40,313		Balance as per last Balance Sheet	68,38,90,607	
Adjustment during the year (give details)	9,79,184		Additions during the year	16,40,95,369	
Schedule No. 6		2,20,19,497	**Less :** Sales during the year		
Other Earmarked Funds :-			Depreciation up to date	26,12,41,499	58,67,44,476
(Created under the provisions of the trust		101014244	**Schedule No. 11**		
deed or scheme or out of the Income)					
			Investments :-		
Balance as per last Balance Sheet	**Opening Balance**		**Note :** The market value of the above		
Grant in Aid - 2 MTR (CAPITAL)		11,90,80,000	investment is Rs.		
Grant in Aid BUILDING		11,97,49,000	**Schedule No. 12**		75,62,25,819
Capital Grant to the Extent of Depriciation	(1,40,44,20,120)		**Furniture & Fixtures :-**		
Additions during the year	(22,03,62,201)	(1,62,47,82,321)	Balance as per last Balance Sheet	2,83,79,023	
			Additions during the year	3,18,383	
Grant in Aid General (Capital) from UGC	2,30,01,74,979		**Less :** Sales during the year	0	
Additions during the year	12,00,00,000		Depreciation up to date	41,46,710	2,45,50,696
Add: Interest	5,49,820				
Less : Subtraction/reversed	0	2,42,07,24,799	**Schedule No. 11**		
Schedule No. 7					
			Loans (Secured or Unsecured) :		
			Good/doubtful		
Any Other Fund - Project Grants			Loans Scholarships		
Schedule No. 8		34,99,08,648	Other Loans		1,36,67,388
			Advances :-		
Loans (Secured or Unsecured) :-			To Trustees		
From Trustees		0	To Employees and other		
From Others		0	To Suppliers/Security Deposits/Prepaid Exp.		1,97,51,527
Liabilities :-			To Lawyers		
For Expenses and other liabilities		36,51,35,285	To Project and Other Receivables		38,60,659
For Projects and Other Payables		10,49,55,146	**Schedule no. 13**		
For Rent & Other Deposits, duties and taxes		31,488			
For Sundry Credit Balances		25,29,869	**Income Outstanding :-**		
Schedule No. 10 &10 A			Rent		
			Interest		
Income and Expenditure Account :-			Other Income		
Balance as per last Balance Sheet	(47,22,45,867)				
Less : Appropriation, if any	4,22,32,114		**Cash and Bank Balances :-**		
			(a) In Savings Account with :		
Add : Deficit during the year	(6,11,82,575)		Bank of Baroda		8,43,68,762
Less Surplus		(49,11,96,328)	In Fixed Deposit Account with -		
Schedule No. 14					
			(b) With the Trustee		
			(c) With the Manager		
			Schedule no. 13		
			Income and Expenditure Account :-		
			Balance as per Balance Sheet		
			Less : Appropriation, if any		
			Add : Deficit as per Income and		
			Less : Surplus Expenditure Account		0
Total Rs......		1,48,91,69,328	Total Rs......		1,48,91,69,328

As per our report of even date;

For AH JOSHI&CO.
Chartered Accountants
FRN: 112396W

A.H. Joshi & Co. Chartered Accountants PUNE 30

The above Balance Sheet to the best of my/our belief contains a true account of the Funds and Liabilities and of the Property and Assets of the Trust.

For Inter-University Centre for Astronomy and Astrophysics

Place : Pune
Dated : 30.04.2022

S.A. Joshi
(Partner)
Membership No. 037772
UDIN: 20037772AAAAHN4011

M.S. Sahasrabudhe
Admin. Officer (Accounts)

N.V. Abhyankar
(Sr. Admin. Offic

Prof. Somak Raychaudhury
Director / Trustee

Chairperson/Trustee
Governing Board

IUCAA, Post Bag 4, Ganeshkhind, Pune 411 007, India.
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