35th ANNUAL REPORT 2022-23

IUCAA

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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145. Uma Papnoi, Department of Physics, Gurukul Kangri (Deemed to be University), Vishwavidyalaya, Haridwar.

146. Rutu M. Parekh, Dhirubhai Ambani Institute of Information & Communication Technology, Gandhinagar, Gujarat.

147. Amit Pathak, Department of Physics, Banaras Hindu University, Varanasi.

148. Kishor D. Patil, Department of Mathematics, Vivekanand Science College, Buldhana, Maharashtra.

149. Madhav K. Patil, School of Physical Sciences, Swami Ramanand Teerth Marathwada University, Nanded, Maharashtra.

150. Bikash C. Paul, Department of Physics, University of North Bengal, Siliguri.

151. Surajit Paul, Raman Research Institute, Bangalore.

152. Devraj D. Pawar, Department of Physics, RJ College, Mumbai.

153. Ninan S. Philip, Artificial Intelligence Research and Intelligent Systems, Thelliyoor, Kerala.

154. Ananta C. Pradhan, Department of Physics and Astronomy, NIT, Rourkela.

155. Anirudh Pradhan, Department of Mathematics, GLA University, Mathura.

156. Ram Prasad Prajapati, School of Physical Sciences, Jawaharlal Nehru University, New Delhi.

157. Anisur Rahaman, Durgapur Government College, Durgapur, West Burdwan.

158. Farook Rahaman, Department of Mathematics, Jadavpur University, Kolkata.

159. Rakhi R., Department of Physics, N. S. S. College, Pandalam, Kerala.

160. Rajesh S.R., Department of Physics, Sanatana Dharma College, Alappuzha, Kerala.

161. Chayan Ranjit, Department of Mathematics, Egra S.S.B. College, Purba, Medinipur, West Bengal.

162. Shantanu Rastogi. Department of Physics, D.D.U. Gorakhpur University, Gorakhpur.

163. C.D. Ravikumar, Department of Physics, University of Calicut, Kozhikode, Kerala.

164. Saibal Ray, Department of Physics, Government College of Engineering and Ceramic Technology, Kolkata.

165. Biplab Raychaudhuri, Department of Physics, Visva-Bharati University, Santiniketan.

166. Prabir Rudra, Department of Mathematics, Asutosh College, Kolkata.

167. Aswathy S., Department of Physics, Providence Women's College, Kozhikode, Kerala.

168. Sunil Kumar S., Department of Physics, IISER, Tirupati.

169. Anirban Saha, Department of Physics, West Bengal State University, Kolkata.

170. Sanjay K. Sahay, Department of Computer Science and Information Systems, BITS - Pilani, Goa.

171. Sandeep Sahijpal, Department of Physics, Panjab University, Chandigarh.

172. Pradyumn Kumar Sahoo, BITS-Pilani, Hyderabad Campus, Hyderabad, Telangana.

173. Eeshankur Saikia, Department of Applied Sciences, Gauhati University, Assam.

174. Gauranga C. Samanta, PG Department of Mathematics, Fakir Mohan University, Balasore, Orissa.

175. Prasant Samantray, Department of Physics, BITS - Pilani, Hyderabad.

176. Biplob Sarkar, Department of Applied Sciences, School of Engineering, Tezpur University, Tezpur.

177. Rathin Sarma, Department of Physics, Rabindranath Tagore University, Hojai.

178. Saumyadip Samui, Department of Physics, Presidency University, Kolkata.

179. Subrata Sarangi, Department of Physics, Centurion University of Technology and Management, Bhubaneswar.

180. Tamal Sarkar, High Energy and Cosmic Ray Research Centre, University of North Bengal, Siliguri.

181. Anjan A. Sen, Centre for Theoretical Physics, Jamia Millia Islamia, Delhi.

182. Asoke K. Sen, Department of Physics, Assam University, Silchar, Assam.

183. Somasri Sen, Department of Physics, Jamia Millia Islamia, Delhi.

184. Anand Sengupta, Department of Physics, IIT, Gandhinagar, Gujarat.

185. T.R. Seshadri, Department of Physics and Astrophysics, University of Delhi, Delhi.

186. Geetanjali Sethi, Department of Physics, St. Stephens College, University of Delhi, Delhi.

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

188. Ranjan Sharma, Department of Physics, Cooch Behar Panchanan Barma University, West Bengal.

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

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

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

192. Dharm Veer Singh, Department of Physics, GLA University Mathura, Uttar Pradesh.

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

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

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

196. Suprit Singh, Department of Physics, Indian Institute of Technology, New Delhi.

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

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

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

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

201. Sourav Sur, Department of Physics &Astrophysics, University of Delhi (North Campus), New Delhi.

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

203. Arun V. Thampan, Department of Physics, St. Joseph's College, Bangalore.

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

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

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

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

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

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

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

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

212. Deepak Vaid, Department of Physics, NIT, Surathkal, Karnataka.

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

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

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

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

The Thirty-Third batch (2022) of Visiting Associates, who were selected for a tenure of three years, beginning August 1, 2022.


Susanta K. Bisoi


Chandrachur Chakraborty


Sumanta Chakraborty


Prasanta K. Das


Archana Dixit


Mayukh R. Gangopadhyay


Prabir Gharami


Chetana Jain


Nagaraja Kamsali


Arun Kenath


Bharat Kumar


Tuhina Manna


Manesh Michael


Mahadevappa Naganathappa


Chandrachani Devi Ningombam


Shibesh K. J. Pacif


Sreejith Padinhatteeri


Rutu M. Parekh


Pradyumn K. Sahoo


Eeshankur Saikia


Geetanjali Sethi


Dharm V. Singh


Ksh. N. Singh


Suprit Singh


Sourav Sur

Appointment of the following visiting associates of the thirtieth batch was extended for 3 years from August 2022

Sheelu Abraham, G. Ambika, Tanwi Bandyopadhyay, Aru Beri, Debbijoy Bhattacharya, Abhirup Datta, K.G Biju, Subenoy Chakraborty, Raghavendra Chaubey, Bhag Chand Chauhan, Kanan Kumar Datta, Sukanta Deb, Moon Moon Devi, Himadri Sekhar Das, Umananda Dev Goswami, Ankur Gogoi, Rupjyoti Gogoi, Aruna Govada, Mamta Gulati, Gurudatt Gaur, Rinku Jacob, Shivappa Bharamappa Gudennavar, Sanjeev Kalita, Md. Mehedi Kalam, Ram Kishor, Nagendra Kumar, Sushant Ghosh, Vinjanampaty Madhurima, Shiva Kumar Malapaka, Bivudutta Mishra, Mubashir Hamid Mir, Aditya Sow Mondal, Barun Kumar Pal, Devraj Damaji Pawar, M. K. Patil, Anirudh Pradhan, Ram Prasad Prajapati, Prince PR, Anisur Rahaman, Biplab Raychaudhuri, Rajesh S.R., Harinder P. Singh, Biplob Sarkar, Tamal Sarkar, Anirban Saha, Anjan Ananda Sen, Surendra Nadh Somala, Anisul Ain Usmani, Nilkanth Dattatray Vagshette, Murli Manohar Verma, Jaswant Kumar Yadav, Lalthakimi Zadeng,

ORGANIZATIONAL STRUCTURE OF IUCAA'S ACADEMIC PROGRAMMES

(As on March 31, 2023)

The Director (Officiating)

R. Srianand

(from January 01, 2023)

The Director

Somak Raychaudhury

(till December 31, 2022)

Dean,
Core Academic Programmes

Dipankar Bhattacharya

R. Srianand

Head,
Computing Facilities

Dipankar Bhattacharya

Sanjit Mitra

Head,
Publications

Aseem Paranjape

Dipanjan Mukherjee

Head,
Instrumentation
A. Ramaprakash

Head,
Library
Durgesh Tripathi

Head,
Teaching Programmes
Gulab Dewangan

Dean,
Visitor Academic Programmes

Kandaswamy Subramanian

A. N. Ramaprakash

Head,
Infrastructural facilities
R. Srianand

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

Head,
Scientific Meetings
Ranjeev Misra

Head,
Public Outreach Programmes
Nishant Singh

Head,
ICARDs
Ranjeev Misra

Head,
Grievance Cell
Gulab Dewangan

DIRECTOR'S REPORT

The main objectives of IUCAA are to provide a centre of excellence within the university-sector for teaching, research and development in Astronomy & Astrophysics (A&A), as well as to promote nucleation and growth of active groups in this area in the universities. The aim is to provide workers from university departments access to state-of-the art astronomical instrumentation, theoretical know-how well equipped laboratories, data centre and high-quality computing facilities. For more than three decades IUCAA has not only achieved these objectives, but has maintained the emphasis on fundamental research and innovative teaching in a wide range of areas of A&A. Over this period IUCAA's interactions with University has also evolved as per the demands of the changing research and technology landscape in the country and abroad. Indian Astronomy is expect to go through a major evolution in the coming decade through (i) our participation in Mega-Science projects such as TMT, SKA and LIGO-India, (ii) ever improving space programs (ADITYA-L1, Daksha, INSIST etc) and (iii) rapidly growing computational resources (e.g NSM). Successful outcomes from all these developments will depend on how well we can develop the required human resources in the available time. Needless to say the trained human resources have to come from universities and here lies the major responsibility of inter-university centres like IUCAA. In consultation with all the stake holders we need to urgently develop short and long term strategic plans for IUCAA to move in this direction.

At present IUCAA's academic staff consists of 27 faculty members (including Emeritus Professors), 4 Adjunct faculty members, 53 PhD students, 25 Post-Doctoral fellows, 41 Scientific and technical staffs and 5 project students. High level of science productivity of IUCAA academic staff is reflected in the fact that during this academic year they have published about 193 papers in the peer reviewed journals. The average impact factor for these publications is 6.0. Very high impact publications include one paper in Nature lead by a PhD student from Tezpur university, two in Nature Astronomy and one in Physical review letter. In collaboration with SPPU-Physics department IUCAA has started a two year M.Sc Physics (Astrophysics). This programme is beginning to attract

talented pool of students. Typically about 15 students enrol each year for this course. The first batch of students from this programme will be graduating in June 2023. It is expected that based on the practical experience gained from this program IUCAA will be in a position to recommend an elaborate M.Sc Physics (Astrophysics) course structure consisting of a wide range of laboratory experiments related to A&A. Given the ever growing activities of IUCAA academics, we are looking forward to filling available vacant posts as soon as possible with talented individuals.

Due to a sustained efforts there is a clear increasing trend in the number of active IUCAA associates with time. Now the total number of associates stands at 216 and IUCAA hopes to bring it close to 300 as soon as possible. In particular, efforts are being made to include people with technical skills that are useful for Astronomy missions from the engineering departments. Due to this increase in the number of associates we also see a strong increase in the number of publications originating from associates and their students. It is recommended by a review committee that IUCAA should set up various working groups constituting of associates and IUCAA faculty in different subject areas. These groups will plan long and short term activities, in particular the effective upgradation and utilisation of various IUCAA programmes and facilities. IUCAA has established about 24 IUCAA Centre for Astronomy Research and Development (ICARD). These were established to contribute to development of upto date course structures and new kinds of experiment/data analysis sessions which can be a part of a starting or existing Astronomy course in a University. Due to Covid-19 restrictions the increase in number of ICARDs is slower than what was planned. We hope to establish more such centres in remote areas of India to increase our reach.

At present SARATI a powerful HPC facility at IUCAA is dedicated to LIGO data analysis and is IUCAA's contribution to International Gravitational Wave Observatory Network (IGWN). SARATI accounts for about 15% of IGWN computing resources. PEGASUS HPC cluster is the dedicated facility made available to the general users of IUCAA and researchers from Indian universities. I am happy to note that these facilities are fully utilised and fractional usage from the university faculty is about 50%. This fraction increases during the holiday periods as several associates could visit IUCAA with their students and focus all their efforts on research work. In particular, PEGASUS HPC is used to perform wide range of MHD and cosmological hydrodynamical simulations. There is a clear demand for increasing the computing resources at IUCAA. It is well documented that, investing in national level large HPCs is absolutely essential to plan innovative observational strategies and interpret the data that will be coming from all Mega-science facilities. Recently, we have made a presentation to the National Supercomputing Mission (NSM) to host a large cluster at IUCAA fully dedicated to the Astronomy & Astrophysics research as part of the NSM-2 project.

Instrumentation lab at IUCAA is building the Solar Ultraviolet Imaging Telescope (SUIT) that is part of ADITYA-L1 solar mission. I am happy to report that the integration and testing of SUIT is completed. It has successfully gone through the vibration and acoustic tests in the end of March 2023. The telescope will be deliver to ISRO to be integrated with Aditya-L1. All the post-launch operation strategy and plans are finalised. Software for pipeline data reduction is being developed at IUCAA. I congratulate our instrumentation team for their efforts and wish them very good luck for a perfect placement of the telescope in its planned location in space.

I am also happy to inform that all the necessary components required to build a high precision atomic clock are developed in the Precision & Quantum Measurement (PQM) laboratory. The next important instrument developed at IUCAA's instrumentation lab is Wide-Area Linear Optical Polarimeter (WALOP). This is mainly funded from external sources through multi-institutional collaboration. Two WALOPs (South and North) have been designed and are being built at IUCAA as part of an international collaboration between Caltech, University of Crete, Greece and SAAO. The data from this instrument will help create a 3D tomographic map of the galactic magnetic fields and dust cloud structure. The first instrument is expected to be ready by end of this year or early next year.

IUCAA is also developing labs and skilled instrumentation team to carryout the commissioning and post commissioning operations of LIGO-INDIA. To address the space requirements for these labs IUCAA is now constructing a new building (called IUCAA-2) in the old science park area. The ground breaking ceremony for this building took place on 24 February 2023 when Prof. Narlikar has formally initiated this building activities.

IUCAA's Computer Centre also hosts ASTROSAT Science Support Cell (ASSC) and Payload Operation Centre (POC) for the CZTI instrument onboard ASTROSAT. ASSC is funded by ISRO to develop and help the user community to effectively analyse the existing ASTROSAT data and

to make proposals for new observations. ASSC has conducted several workshops / data analysis schools in the past year. The main highlight is that since January 2022 there are 80 refereed publications using ASTROSAT data, 26 of them were co-authored by IUCAA members, making IUCAA the leading contributor to the science emanating from ASTROSAT. IUCAA is playing active role in generating the list of GRBs detected using CZTI and maintaining the light-curves and derived parameters of the detected GRBs in an user friendly manner. I am happy to note that recently the number of GRBs identified with CZTI has reached 500. The experience gained in running the POC for CZTI will come in handy when we set up POC for SUIT.

Astronomy Centre for Educators (ACE) of IUCAA includes Teaching Learning Centre (TLC), National Resource Centres (NRC) and International Astronomical Union's office of education (IAU-OAE). The main activities performed during this year include (i) conducting an online seminar on education where India's leading educationalists have participated and discussed about various innovating teaching methods to efficiently communicate higher education to students and general public; (ii) conducted a Astronomy, Science & Society Workshop 2022-2023 for faculty members from different discipline in collaboration with Maharashtra state faculty development authority. (iii) Conducted a antenna design competition to detect radio signal from Jupiter (in collaboration with Fergusson College Pune). There were 20 colleges participating in this activity and three best designs were selected as the best designs and were given prizes. (iv) the centre also regularly conducts Refresher courses and Radio astronomy winter schools. At present ACE is focused on school and college education. With an appropriate planning, we hope to use the facilities established at ACE to offer a wide range of advanced A&A courses that students from different universities can credit through academic credit banks under the National Education Policy 2022 (NEP2022).

As a part of LIGO-India activities IUCAA is involved in different Education and Public Outreach (EPO) programmes. One of the main activities is the creation of content, coordination and posting of LIGO-India social media (Facebook, Instagram, Twitter, Youtube). LIGO-EPO members regularly engage with local administration regarding LIGO project and coordinate various activities with the general public, school and college students in different villages around Hingoli. These activities are extremely important to educate the local public so that all developments over time in this area happens without increasing the seismic noise level.

Post Covid19, following our tradition this year we have opened our campus to the general public during the National Science Day (NSD). About 10,000 people visited IUCAA on the Open Day. As part of the NSD, IUCAA has conducted science themed competitions in Pune District rural schools (on 11 February 2023) and for Pune City schools (on 25 February 2023). Students from 70 schools have participated in these competitions (like essay writing, drawing, model making and quiz). We have arranged exciting talks, engaging posters, demonstrations, video shows and live solar viewing on 28 February 2023. The unique themes for this year are (i) Studying the Sun with Aditya-L1, (ii) Inspiring the future women of science, (iii) Astro-Mythbusters and (iv) know our shared sky – live skywatch. In the afternoon of the science day Prof. Narlikar, Prof. Ajit Kembhavi, Prof. Surhud More and myself answered the questions from the general public through our programme "Ask the Scientist". I would like to express my sincere thanks to regular and contractual staff of IUCAA to make this annual activity a grand success.

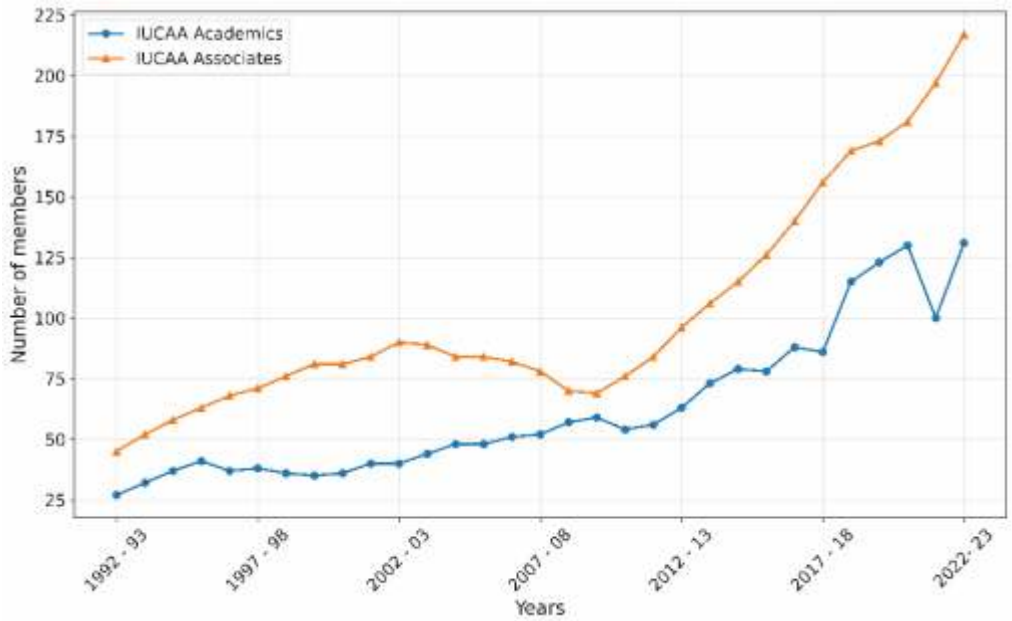
I would like to thank IUCAA members and my seniors for their help in performing my duty as the officiating director of IUCAA. I would also like to express thanks to our mentors, our Governing Board with Dr K. Kasturirangan as Chair, and our Council, chaired by Dr M. Jagadesh Kumar. I also acknowledge the help, advice and support from the University Grants Commission and its officers and staff, and from the Ministry of Education of the Government of India.

R. SRIANAND

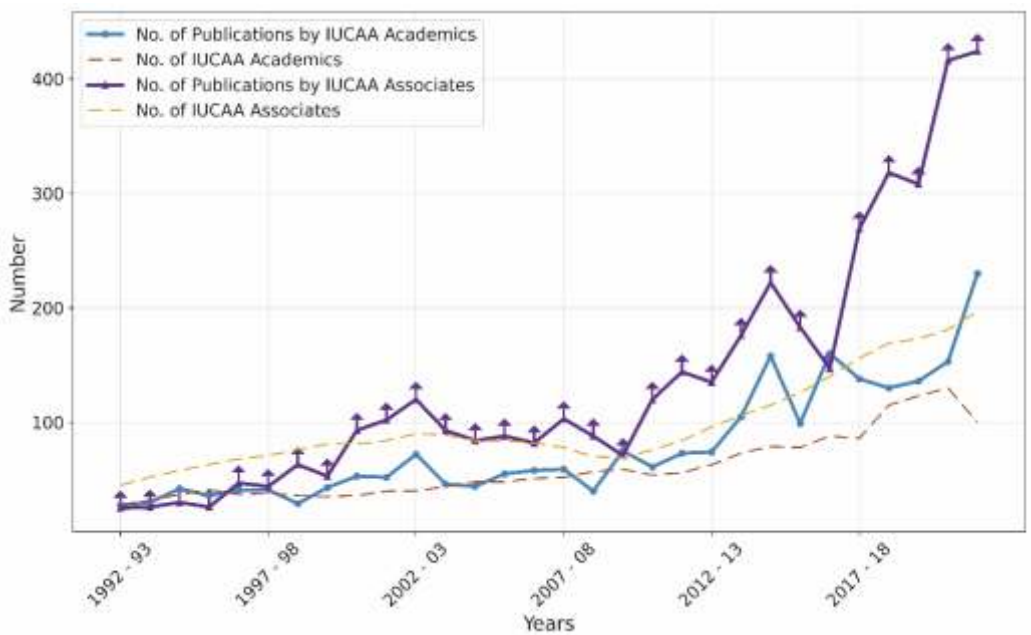
Director Officiating, IUCAA

IUCAA IN NUMBERS

IUCAA Family

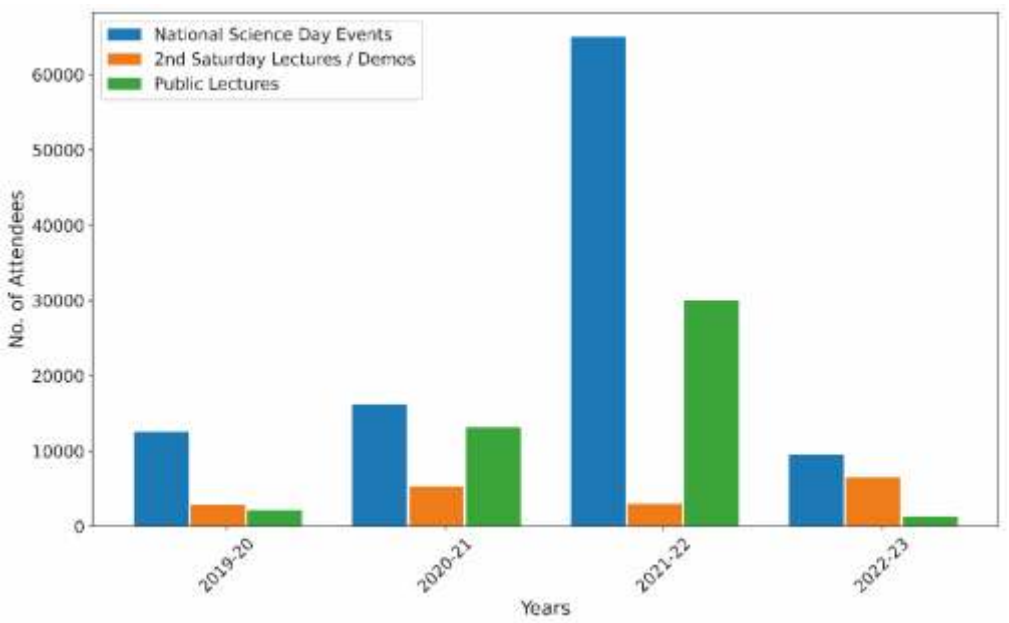


The figure shows the evolution of the number of academics of IUCAA and Visiting Associates.

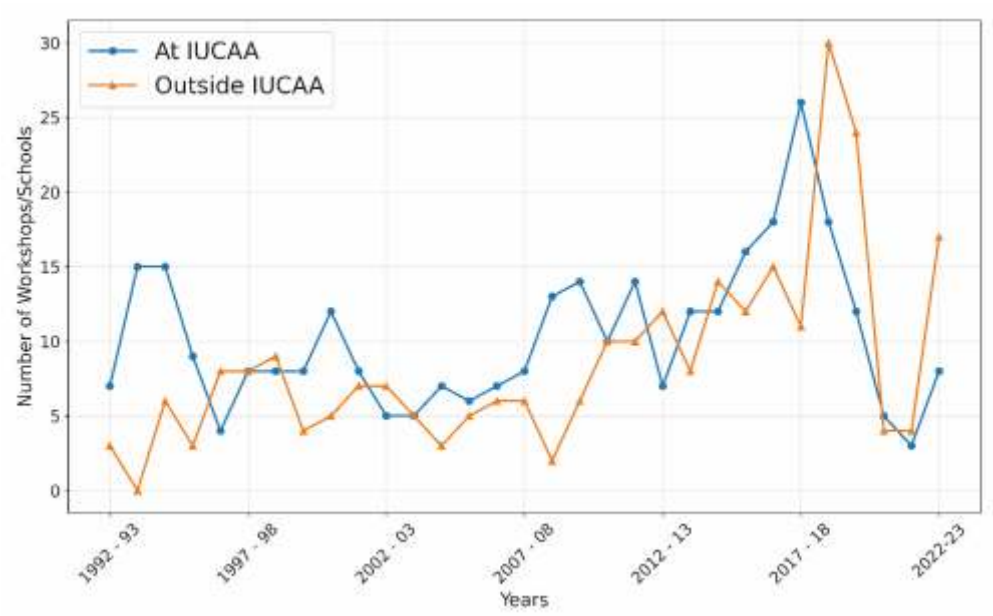


Publications across the year

The number of Publications by IUCAA visiting Associates are underestimated

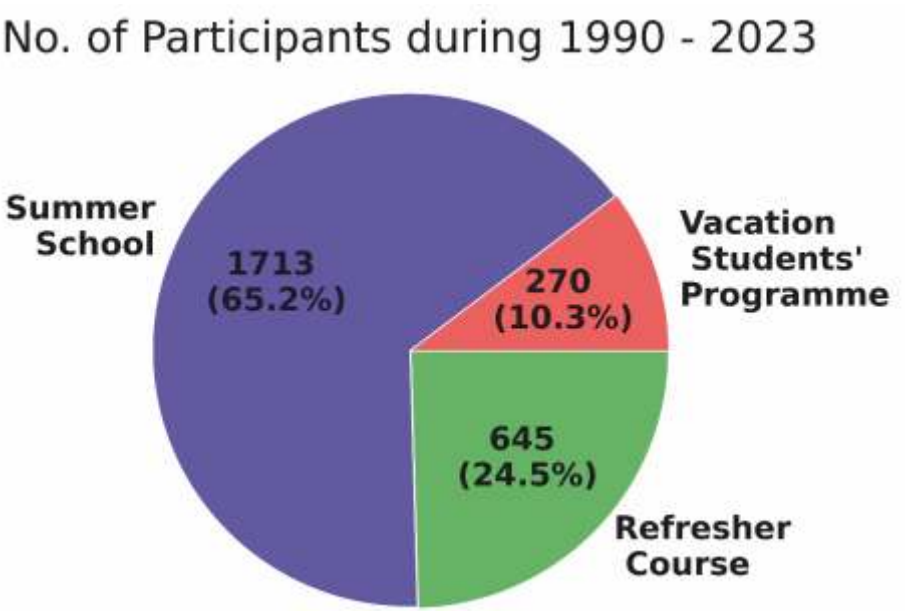


Public Outreach Events at IUCAA over the years



Workshops / Schools in IUCAA and Outside IUCAA.

Organizing such workshops and schools at universities and ICARDS helps foster Astronomy and Astrophysics in India, which is one of the primary prerogatives of IUCAA.



Summer Programmes at IUCAA: IUCAA's Summer Programmes provide intensive courses in Astronomy and Astrophysics over the span of few weeks to researchers at the undergraduate and post-graduate levels through the Summer School and Vacation. Students Programme, as well as to teachers from Universities through the Refresher Courses.

RESEARCH HIGHLIGHTS

AstroSat: A Multi-wavelength exploration of the Universe

India's first multi-wavelength satellite, AstroSat, marks a significant milestone in the country's space exploration efforts. It was launched by the Indian Space Research Organisation (ISRO) on September 28, 2015. AstroSat is specially designed to study high energy phenomena, detect transient sources, measure neutron star's magnetic fields and conduct deep field surveys in the ultraviolet frequencies. It has five astronomy payloads onboard for simultaneous multi-band observations: Ultraviolet Imaging Telescopes (UVIT), Large Area X-ray Proportional Counters (LAXPC), Soft X-ray Telescope (SXT), Cadmium-Zinc-Telluride coded-mask Imager (CZTI) and Scanning Sky Monitor (SSM). These instruments are being handled by different payload operation centers (POCs), situated at various institutes at different parts of the country. The role of the Inter-University Centre for Astronomy and Astrophysics (IUCAA) for AstroSat has been a crucial one. IUCAA hosts the POC for the CZTI instrument. CZTI is designed to detect high-energy X-rays and gamma rays from celestial sources. One of the most significant accomplishments of CZTI has been the detection of over 550 Gamma Ray Bursts (GRBs), which are explosive events accompanying the birth of Black Holes. The CZTI team, led by Prof. Dipankar Bhattacharya and Prof. Varun Bhalerao, has continuously improved the search and detection methods, involving young scientists, including undergraduate students and Ph.D. scholars, who actively contribute to the analysis of the data. An important feature of CZTI is its capability to measure the polarization of high energy X-rays, which is instrumental in unraveling the dynamics just outside newly formed black holes. This unique ability distinguishes CZTI from flagship GRB missions like NASA's Neil Gehrels Swift Telescope and the US-Europe Fermi Space Telescope. Till date the CZTI team has reported the detection of strongly polarized emission from several GRBs and has deduced the source geometry and magnetic orientation based on these results (Chattopadhyay et al 2022 ApJ 936, 12). Apart from this, the AstroSat Science Support Cell (ASSC) was also set up as a joint venture of the Indian Space Research Organisation (ISRO) and IUCAA with the primary purpose of facilitating the use of AstroSat, both for making observing proposals and for utilizing archival data. In this regard, the ASSC website provides different required tools, documentation and updates related to the instruments onboard AstroSat. ASSC also runs a help desk to address user queries, provides utility tools, and disseminates analysis software through a consolidated web portal. It also maintains the AstroSat Proposal Processing System (APPS) deployed at ISSDC, a software platform central to the workflow management of AstroSat operations. In addition, ASSC organizes meetings, workshops and webinars from time to time to train the users in utilizing the AstroSat archival data and writing proposals. AstroSat has already completed 7 years of successful operation and is aiming to go far beyond. The successful operation of AstroSat has established India as a significant player in the field of multi-wavelength astronomy and continues to contribute to groundbreaking discoveries in astrophysics.

Till date, the number of refereed publications using AstroSat observations has surpassed 350. In addition, more than 22 PhD theses (both nationally and internationally) have been produced based on scientific conclusions obtained from AstroSat observations. Some of the important research undertaken by IUCAA members using AstroSat data are highlighted below.

AstroSat View of Galaxies at Z=0.40-0.75 in the GOODS-North-Field

The internal dust extinction of a galaxy can be inferred from the measurement of its UV continuum slope (β). There have been several studies that computed β of galaxies starting from the nearby universe up to redshift z~10. The observed β–z relation signifies a gradual dust enrichment in galaxies with cosmic time. Due to the lack of wide-field near-UV imaging and higher angular resolution than what was possible by GALEX satellite, the β measurement of galaxies from z = 1 to 0 has not been explored well; except the very local galaxies. Hence, a study has been carried out by IUCAA Astronomers (Chayan Mondal and Kanak Saha) along with their international collaborators using the high-resolution NUV images of the GOODS-North field observed with AstroSat/UVIT to fill this ~8 Gyr age gap in the global β – z relation. Combining with HST F275W, F336W, and KPNO U bands, the AstroSat/UVIT data has helped to estimate β of 465 galaxies between redshift 0.40 and 0.75. The mean (median) and 1 σ scatter in the observed β are found to be – 1.33±0.07 (–1.32) and 0.60 within the considered redshift range. The β measurements found from this study add new data points to the least-explored redshift regime, further reinforcing the gradual reddening of the galaxy UV continuum with cosmic time. The sensitivity of UVIT instrument allowed to sample β of faint galaxies down to M1500=–15.6 mag (i.e., 0.028L* at z=0.5). No specific trend between β and M1500 for the entire luminosity range –21< M1500<–15 mag was observed, although the majority of the most luminous galaxies (M1500<–19 mag) are found to have relatively redder slopes. This study highlights the unique capability of AstroSat/UVIT near-UV imaging to characterize the rest-frame far-UV properties of galaxies at redshift z ~ 0.5, and is published in the Astrophysical Journal (ApJ).

Insights to the intrinsic accretion disk emission from Seyfert type 1 AGN using AstroSat/UVIT

A group of IUCAA Astronomers (Shrabani Kumar, G. C. Dewangan and Prakash Tripathi) along with their national and international collaborators have carried out a study on the accretion disk emission from a sample of eight Seyfert 1 – 1.5 active galactic nuclei (AGN) using far ultraviolet (1300 – 1800 Å) slit-less grating spectra acquired with AstroSat/UVIT. The emission from accretion disk is contaminated and

suffers extinction on its way to the telescope. They corrected for the Galactic and intrinsic extinction, contamination from the host galaxies, narrow and broad-line regions, Fe II emission, and Balmer continuum to derive the intrinsic continua. The astronomers have also used the HST COS/FOS spectra to account for the emission/absorption lines in the low-resolution UVIT spectra, and found generally redder power-law ($f_\nu \propto \nu^\alpha$) slopes ($\alpha \sim -1.1$ - 0.3) in the far UV band than predicted by the standard accretion disk model in the optical/UV band. Different accretion disk models such as multi-temperature disk blackbody (DISKBB) and relativistic disk (ZKERRBB, OPTXAGNF) have been fitted to the observed intrinsic continuum emission. They measured the inner disk temperatures (~ 3.6 - 5.8 eV) using the DISKBB model for seven AGN. These temperatures are lower than the peak temperatures predicted for standard disks around maximally spinning supermassive black holes accreting at Eddington rates. The inner disks in two AGN, NGC 7469 and Mrk 352, appear to be truncated at ~ 35 - 125rg and 50 - 135rg, respectively. While these results show that the intrinsic FUV emission from the AGN are consistent with the standard disks, it is possible that UV continua may be affected by the presence of soft X-ray excess emission, X-ray reprocessing, and thermal Comptonisation in the hot corona. Hence, the astronomers have suggested that joint spectral modeling of simultaneously acquired UV/X-ray data will be required to further investigate the nature of accretion disks in AGN. This part of the work is accepted for publication in the Astrophysical Journal (ApJ).

Investigating the dynamics of Quasi-periodic Oscillations (QPOs) using AstroSat data

The dynamics of transient Black Hole X-ray binaries and their luminosity outbursts during their evolutionary process have intrigued researchers. These systems transition through hard and soft spectral states, each displaying varying variability patterns and the emergence or disappearance of localized peaks in the power density spectrum. These localized peaks, known as Quasi-periodic Oscillations (QPOs), are believed to originate in the inner accretion regions and provide valuable insights into the extreme gravity near black holes. However, the exact origin of QPOs remains a subject of ongoing research.

In recent studies, national researchers including Dr. Akash Garg and Prof. Ranjeev Misra from IUCAA, along with Dr. Somasri Sen from Jamia Millia Islamia University, have developed a generic technique to model the energy-dependent properties of QPOs by analyzing variations in the radiative components of the time-averaged photon spectrum. They applied this technique to study low-frequency QPOs detected through an extensive collection of AstroSat observations of the black hole system MAXI J1535-571.

During their analysis, the researchers fitted the spectra emitted from a truncated disc with an inner hot corona. They investigated the dependence of QPO frequency on other spectral parameters and modeled the energy-dependent root mean square (rms) and time lag of the QPOs. Their objective was to identify the physical spectral parameters responsible for the observed QPO behavior.
Interestingly, the researchers observed that the time lag between hard and soft photons is negative for QPO frequencies above 2.2 Hz, while it becomes positive for lower values. This behavior, previously seen only in the black hole system GRS 1915+105, represents a significant finding. By modeling the fractional rms and time lag, the researchers discovered a correlated variation among the accretion rate, inner disc radii, and coronal heating rate. They observed that the coronal heating rate exhibits a time lag compared to the other two parameters for QPO frequencies below 2.2 Hz. However, for higher frequencies, the sign of the time lag changes, implying that the coronal heating variation precedes the accretion rate variation. This finding suggests different dynamic origins for QPOs based on the observed time lags. Nevertheless, the researchers emphasize that the underlying scenario may be more intricate and warrant detailed modeling.
The research findings have been published in the MNRAS journal, contributing to the ongoing understanding of QPO dynamics and their implications in the realm of astrophysics.

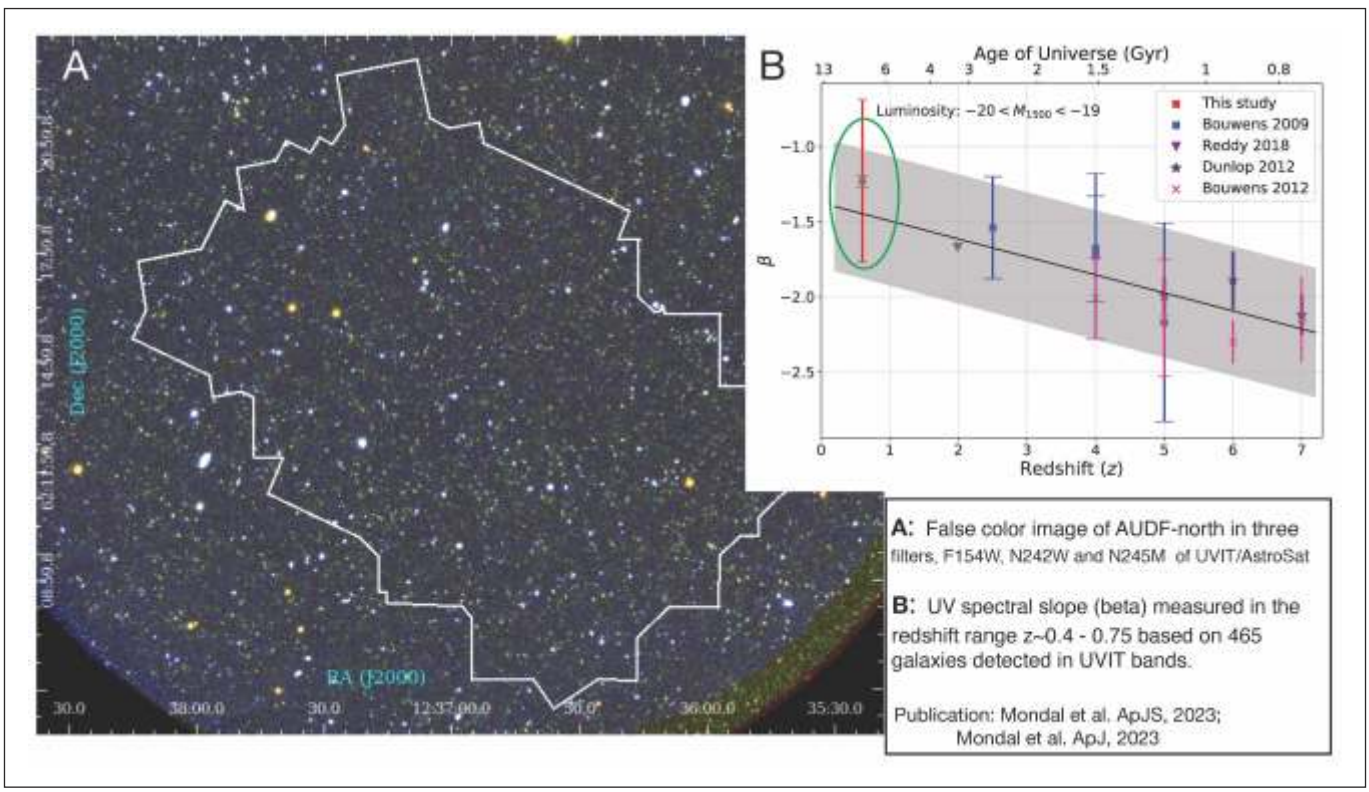
Witnessing the 'live' formation of dwarf galaxies with AstroSat's ultraviolet-eye

Galaxies are the basic building blocks of the Universe- they come in all sizes. Our galaxy, the Milky Way, is one of the giant galaxies with billions of stars, but little current star formation. Giant galaxies such as ours are surrounded by tens of dwarf galaxies- irregular in shape, often forming stars. As we look backwards in time we see that galaxies were smaller and more irregular (since light takes time to travel, a galaxy seen 3 billion light-years away from a Universe that is 3 billion years younger). How these dwarf and giant galaxies assemble their stars and evolve into modern-day galaxies, like our own Galaxy, is still one of the major puzzles.

A recent study by a team of scientists using AstroSat shows how the star-forming clumps in the outskirts of a dwarf galaxy migrate towards the central region and contribute to its growth in mass and luminosity. This process that is now witnessed in several dwarf galaxies is a very important link in understanding the bigger picture of galaxy growth and evolution. The key challenge has been to firmly establish the detection of these faint, extremely blue, star-forming clumps which are very far away to see although they have a million solar masses of material within them. At slightly larger distances, the UVIT would not resolve these galaxies and we do not have an example of an extended disk seen in UV in any present-day dwarf galaxies. The redshift (cosmological distance) of these 12 dwarfs has been just optimal to probe these blue clumpy structures in their outskirts. The discovery was made by an international team of astronomers from India, the USA and France.

The study was conceived by Professor Kanak Saha at the Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, and was published as

a research paper on July 20, 2022, by the main journal of Nature [DOI: https://doi.org/10.1038/s41586-022-04905-9]. Prof. Kanak Saha says "We are witnessing the 'live' formation of these far-way dwarf galaxies! UVIT's resolving power and deep field imaging techniques have been the key to spotting some very young, large star-forming clumps. These form on the periphery and then spiral into the visible (optical) boundary of their galaxy within a billion years timescale thus adding to the growth of the galaxy. A good part of our research work consists of meticulously calculating the time required for the clumps to migrate inside the galaxy". He also emphasized that the key challenge has been to firmly establish the detection of these faint, extremely blue, star-forming clumps which are very far away to see although they have a million solar masses of material within them. At slightly larger distances, the UVIT would not resolve these galaxies and we do not have an example of an extended disk seen in UV in any present-day dwarf galaxies. The redshift (cosmological distance) of these 12 dwarfs has been just optimal to probe these blue clumpy structures in their outskirts.



A: False color image of AUDF-north in three filters, F154W, N242W and N245M of UVIT/AstroSat

B: UV spectral slope (beta) measured in the redshift range z~0.4 - 0.75 based on 465 galaxies detected in UVIT bands.

Publication: Mondal et al. ApJS, 2023; Mondal et al. ApJ, 2023

IUCAA IN NEWS

Neawspaper clippings for the period April 01, 2022, to March 31, 2023

1. **54 countries, 277 publications 3000 users: At 7, India's AstroSat leaps ahead.**
   Indian Express, Pune, September 29, 2022, page no. 11

2. **Study by IUCAA scientists, collaborators on supermassive black holes featured on cover of international journal.**
   Indian Express, Pune, May 03, 2022, Page no. 6

3. आता 'आयुका २.०': नव्या संशोधनासाठी विद्यापीठात दोन वर्षांत अत्याधुनिक इमारत
   महाराष्ट्र टाइम्स, प्लस, पुणे, सप्टेंबर २९, २०२२, पान क्र. १

4. **What Webb's deep field image shows, and why is it epochal.**
   Indian Express, Pune, July 13, 2022, Page no. 14

5. 'जेम्स वेब' ने टिपली प्राचीन विश्वाची प्रतिमा
   सकाळ, पुणे, जुलै १३, २०२२, पान क्र. ५

6. **NASA's Cosmic Show**
   Times of India, Pune, July 13, 2022, Page no. 20

7. 'लायगो' ला प्रतीक्षा 'आर्थिक' तरतुदीची
   सकाळ, सारांश, पुणे, फेब्रुवारी २८, २०२३, पान क्र. ८

8. 'जेम्स वेब' द्वारे विश्वदर्शन
   महाराष्ट्र टाइम्स, पुणे, जुलै १३, २०२२

9. आकाशगंगेच्या कक्षेबाहेर प्रथमच दिसली ताऱ्यांची निर्मिती
   पुढारी, पुणे, जुलै ३०, २०२२, पान क्र. १

10. 'ऍस्ट्रोसॅट' ने टिपली लघु दीर्घिका
    सकाळ, पुणे, जुलै ३०, २०२२, पान क्र. ९

11. **Astronomers discover huge black hole spewing fiery jet at another galaxy.**
    Times of India, Pune, October 13, 2022, Page no. 2

IUCAA ACADEMIC CALENDAR

Annual Events at IUCAA 2022 - 23

Refresher Course on Astronomy and Astrophysics
Date: May 16 - June 16, 2022

Introductory Summer School on Astronomy and Astrophysics
Date: May 16- June 16, 2022

Vacation Students' Programme
Date: This is an ongoing programme

Foundation Day
Date: December 29, 2022

National Science Day
Date: February 28, 2023

Events at IUCAA 2022 - 23

Meeting on space based gravitational wave observatories
Date: July 15 - 16, 2022
Coordinators: Sanjit Mitra

Discussion Meeting on AstroSat Calibration
Date: August 23 - 24, 2022
Coordinators: AstroSat Science Support Cell

Indo-French School (IFAS7) on Spectroscopy and Spectrographs
Date: November 21 - 27, 2022
Coordinators: Kanak Saha

Constancy of the fundamental "constants?"
Date: December 01 -02, 2022
Coordinators: Subhadeep De | Sowgat Muzahid
Schedule: Lecture Schedule

GEANT4 Physics Applications Workshop
Date: December 05 - 09, 2022
Coordinators: Gulab Dewangan | Shriharsh Tendulkar (DAA, TIFR)

IUCAA - NCRA Radio Astronomy Winter School - 2022
Date: December 13 - 23, 2022
Coordinators: Prakash Arumugasamy | Jameer Manur | Subhashis Roy (NCRA, Pune)

The Cosmic Crowd in the Universe
Date: December 19, 2022
Coordinators: Kanak Saha | R. Misra | T. D. Saini (IISc)

National Workshop on Galactic inflows and outflows on all Scales (GALFLOWS)
Date: February 02 - 05, 2023
Coordinators: Dipanjan Mukherjee| Sowgat Muzahid

Events Outside IUCAA 2022 - 23

Introductory workshop on Active Galaxies
Date: August 10 - 11, 2022
Place: Farook College, Calicut
Coordinators: Naseef Mohammed | G. Dewangan

High energy emission from Active Galactic Nuclei
Date: August 12 - 14, 2022
Place: Farook College, Calicut
Coordinators: Naseef Mohammed | G. Dewangan

Workshop on UVIT Data Analysis on Galaxies
Date: August 24 - 26, 2022
Place: The Cochin College, Kerala
Coordinators: Sathya Narayanan K | Kanak Saha

One Day Seminar on Astrophysics
Date: August 30, 2022
Place: Aquinas College, Edakochi, Ernakulam, Kerala
Coordinators: Joe Jacob | R. Misra

Seminar on Current Status of Cosmology
Date: September 19 - 21, 2022
Place: SGT University, Delhi- NCR
Coordinators: M. Sami | R. Misra

Workshop on "Science and Technology in Astronomy Research (STAR 2022)"
Date: October 15 - 18, 2022
Place: Pt. R.S. University, Raipur
Coordinators: Nand Kumar Chakradhari | R. Misra

North-East Meet of Astronomers (NEMA VIII)
Date: November 21 - 23, 2022
Place: Manipur University, Manipur
Coordinators: Yugindro Kangujam | A. Meitei | R. Misra

Seminar in GR and Astrophysics
Date: November 21, 2022
Place: ICARD, North Bengal University, Silguri
Coordinators: Bikash Paul | R. Misra

Seminar in GR and Astrophysics
Date: November 22 - 23, 2022
Place: Cooch Behar Panchanan Barma University (CBPBU), Cooch Behar
Coordinators: Ranjan Sharma | R. Misra

Workshop of General Relativty and Cosmology
Date: November 24 - 26, 2022
Place: GLA University, Mathura
Coordinators: Anirudh Pradhan | Aseem Paranjape

Introductory Workshop on Astronomy and Astrophysics for Women Students
Date: December 06 - 08, 2022
Place: Department of Physics, Mar Thoma College, Kerala
Coordinators: Sheelu Abraham | Annu Jacob

International Workshop on Celestial Mechanics and Dynamical Astronomy (IWCMDA-2023)
Date: January 06 - 08, 2023
Place: Central University of Rajasthan, Ajmer
Coordinators: Ram Kishor | Kanak Saha

Beginning Astronomy: Start a data-driven journey
Date: February 02 - 04, 2023
Place: Manipal Academy of Higher Education, Manipal
Coordinators: Debbijoy Bhattacharya | Souradeep Bhattacharya | Preetish Mishra | Chayan Mondal | R. Misra

AWARDS AND DISTINCTIONS

- **Debarati Chatterjee**
  On her article [https://doi.org/10.1103/PhysRevC.106.035801] being highlighted as Editor's Suggestion for the journal Physical Review C written along with her Ph.D. student Suprovo Ghosh and collaborators Kauan Marquez, Mateus Pelicer and Prof. Debora Menezes from UFSC, Florianopolis, Brazil, along with colleagues J. Peterson and Prof. V. Dexheimer from Kent State University [Ohio, USA] and selected for inclusion in the American Physical Society's outreach to the press.

  The French coverage of the article appeared in the October issue of Pour La Science [the French version of the American magazine Scientific American] and received international recognition:

  https://www.pourlascience.fr/sd/astrophysique/des-particules-exotiques-au-coeur-des-magnetars-24266.php

- **Surhud More**
  On receiving the Best Paper award for 2022 by Publications of the Astronomical Society of Japan: GOLDRUSH. II. Clustering of galaxies at $z \sim 4$–6 revealed with the half-million dropouts over the 100 deg^2 area corresponding to 1 Gpc^3.

- **Sowgat Muzahid**
  On his proposal titled *the role of gaseous halos in galaxy evolution*, being awarded a travel grant for three years under the Indo-Italian Executive Programme of Scientific and Technological Cooperation, 2022. The associated news article can be found here–

  [https://indianexpress.com/article/cities/pune/3-scientists-pune-selected-indo-italian-research-7732620/ | His proposal titled *Connecting the ISM and CGM properties of galaxies at cosmic noon* being awarded 23 hours of observations in the Very Large Telescope [VLT] in the Cycle P111 [Proposal ID: 111.24ZE.001].

- **J. V. Narlikar**
  On being conferred with the ASI Govind Swarup Lifetime Achievement Award [2022] by the Astronomical Society of India.

- **Aseem Paranjape**
  on being appointed as a Regular Associate of ICTP, Trieste, from 01 Jan 2023 to 31 Dec 2028.

- **Varun Sahni**
  on receiving the 2023 Vaidya Raychaudhuri Endowment Award.

- **Kandaswamy Subramanian**
  on being elected as Fellow, National Academy of Sciences on receiving the Carl Friedrich von Siemens Research Award of the Alexander von Humboldt Foundation

RESEARCH GRANTS AND FELLOWSHIPS

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

Souradeep Bhattacharya
- DST-INSPIRE Faculty Fellowship

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

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

Sanjeev Dhurandhar
- NASI Fellowship

Samir Dhurde
- International Astronomical Union (OAO Grant)

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

Sanjit Mitra
- DST Swarna Jayanti 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 (IFCPAR) 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
- Institute of Plasma Physics Crete WALOP N
- Infosys Foundation Grant for Resurgent Caltech – IUCAA Collaboration for Advanced Instrument Development and Scientific Discoveries
- Institute of Arizona LBT1

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

Varun Sahni
- DST J.C. Bose Fellowship

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

PUNE KNOWLEDGE CLUSTER

About Pune knowledge Cluster

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

Vision

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

Mission

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

Key Achievements (since April 2022)

- PKC has raised over Rs. 6 CR in the form of grants and CSR funding from organizations like Rockefeller Foundation, Hindustan Unilever, Cummins Foundation, Lenovo India and BASF Chemicals India, for its various projects.
- PKC has signed MoUs with 18 organizations including academia, R&D labs, industries, NGOs, and incubation centres.
- PKC has hosted meetings with the German, Swedish and Norwegian Consulates to foster collaborations in the areas of water management, waste management and energy.

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 has the following ongoing projects under this vertical:

- COVID-19 Genomic Surveillance
- COVID-19 Environmental Surveillance
- Retrospective clinical study for COVID-19 (Supported by Rockefeller foundation)
- COVID-19 Long Term Immunogenicity Study (Supported by Hindustan Unilever)
- COVID-19 Clinical Database
- Dengue Incidence study
- Anti-microbial Resistance (AMR) study

Partners: Projects are implemented in a collaborative manner between the hospitals, R&D labs and city administration. Key partners include – IISER Pune, CSIR-NCL, BJMC, KEM, Symbiosis, Genepath, Noble Hospital, STRAND life sciences, EPIC-HIM, ARTPARK, PMC, PCMC, NCBS, Ashoka University, MUHS

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 the following ongoing projects:

- **Technology-driven Urban Forestry Programs** such as ConnecTree and TreeVerse, to preserve and improve tree cover in Pune City. PKC is working to create technology platforms to automate tree census, improve citizen engagement in tree plantation and adoption and build a computational platform for carbon sink estimation.
- **Carbon Accounting in Campuses:** Through this program, PKC encourages academic campuses and Industry premises to account for their Carbon emissions through efficient data collection; and imbibe practises enabling Carbon Neutrality.
- **Sustainable Afforestation Programs**: Through these programs, PKC aims to initiate forest landscape restoration projects designed to provide a sustained livelihood by meeting raw material requirements of industry on a short, medium as well as long term basis. PKC currently plans to undertake these programs at three different locations in and around Pune.
- **Biomass white paper:** PKC, along with partner organizations is in a process of creation of white paper for increasing biomass on degraded and fallow lands, to augment the green energy demands of the nation. The aim is present this white paper to relevant stakeholders for conversion into a policy document.
- **Water Action Plan for Pune Metropolitan Region**: Aligned to the **National Water Mission**, PKC is preparing a sustainable water Management Plan for the Pune Metropolitan Region, 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.

- For this, a feasibility study has been started for PCMC, in collaboration CPC analytics.

- **Hydrogen Valley in Pune region:** PKC is working towards developing a Hydrogen Cluster in Pune region to foster

collaborations between industries and R&D organizations for developing technologies for Green Hydrogen production, storage, transport and capacity building.

Work with local administration: PKC works actively with PMC, PCMC and Pune Zilla Parishad 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: Pune Smart City, CEE India, WRCS, Genesys, Maharashtra Forest Department, Samuchit Environment, Gokhale Institute of politics and economics (GIPE), CPC Analytics, Kishore Pumps, Biofuel circle, Bhartiya Agro Industries Foundation (BAIF), CSIR-NCL, IORA Ecological Solutions Pvt. Ltd., CDSA, ACWADAM, DHI (Denmark), Water Valley Denmark, Clean Cluster, DTU (Denmark)

Key Future plans:

- **Centre for Water** – Building a Centre for water management, technology deployment, and policy in collaboration with Water Valley, Denmark
- **CoE for Carbon Sequestration & Renewable Energy** – Building a centre 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 1200+ citizens have analyzed over 2 GB of data (images of galaxies) on PKC's platform. PKC is also trying to develop AI algorithms based on citizens' response.

Apart from this, PKC is building collaborative projects between BIG Data and AI experts, chemists, and biologists to encourage inter-disciplinary research; and building an open-access dataset where capabilities of differently abled citizens will also be leveraged to collect scientific data.

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 7 inter-disciplinary training programs and workshops with over 350 beneficiaries, and 26 citizen-centric talks with over 2400 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 3 ongoing STEM projects:

- Teach with Tech (supported by Lenovo India)
- WEnyan – a mentoring and scholarship program for women in chemistry and sustainability (supported by BASF Chemicals India)
- Platform for Gamified Learning in Chemistry and STEM Education (supported 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.

RESEARCH BY IUCAA FACULTY 2022-2023

Classical and quantum gravity

Gravitation, and quantum theory, as emergent phenomena

There must exist a reformulation of quantum field theory, even at low energies, which does not depend on classical time. The octonionic theory being developed by **T. P. Singh** and collaborators proposes such a reformulation, leading to a pre-quantum pre-spacetime theory. The ingredients for constructing such a theory, which is also a unification of the standard model with gravitation, are : (i) the pre-quantum theory of trace dynamics – a matrix-valued Lagrangian dynamics, (ii) the spectral action principle of non-commutative geometry, (iii) the number system known as the octonions, for constructing a non-commutative manifold and for defining elementary particles via Clifford algebras, (iv) a Lagrangian with E8×E8 symmetry. The split bioctonions define a sixteen dimensional space (with left-right symmetry) whose geometry (evolving in Connes time) relates to the four known fundamental forces, while predicting two new forces, SU(3)grav and U(1)grav. This latter interaction is possibly the theoretical origin of MOND. Coupling constants of the standard model result from left-right symmetry breaking, and their values are theoretically determined by the characteristic equation of the exceptional Jordan algebra of the octonions. The quantum-to-classical transition, precipitated by the entanglement of a critical number of fermions, is responsible for the emergence of classical spacetime, and also for the familiar formulation of quantum theory on a spacetime background. [https://www.preprints.org/manuscript/202302.0253/v1 to be published in J. Phys. Conf. Series (2023)]

The exceptional Jordan algebra, and its implications for our understanding of gravitation and the weak force

The exceptional Jordan algebra is the algebra of 3×3 Hermitian matrices with octonionic entries. It is the only one from Jordan's algebraic formulation of quantum mechanics which is not equivalent to the conventional formulation of quantum theory. It has often been suggested that this exceptional algebra could explain physical phenomena not currently explained by the conventional approach, such as values of the fundamental constants of the standard model of particle physics, and their relation to gravitation. We show that this is indeed the case; and this also unravels the connection between general relativity and the weak force. The exceptional Jordan algebra also predicts a new U(1) gravitational interaction which modifies general relativity, and which provides a theoretical basis for understanding the Modified Newtonian Dynamics (MOND). [https://arxiv.org/abs/2304.01213v1 submitted to the Gravity Research Foundation essay contest (2023)]

Computational Astrophysics

Predicting observable signatures of jet-ISM interaction

Relativistic jets from supermassive blackholes can strongly interact with dense gas distribution in galaxies. Scientists from IUCAA have demonstrated this earlier (Mukherjee et al. 2018) through state of the art numerical simulation of relativistic jets breaking out of the confines of a galaxy. In a recent work, led by IUCAA researchers, **M. Meenakshi** and **Dipanjan Mukherjee** , it has been demonstrated that such interactions of jets with their host galaxy can be detected with telescopes that spatially resolve such interaction (see Figure 1). It has been demonstrated that jets can significantly stir the gas in their host galaxies, inducing turbulence in the gas and launching fast outflows. Jets inclined to the gas disc of its host are found to be confined for longer times, and consequently couple more strongly with the disc gas. This results in prominent shocked emission and high-velocity widths, not only along the jets path, but also in the regions perpendicular to them. Strong interaction of the jet with a gas disc can also distort its morphology. However, after the jets escape their initial confinement, the jet-disc coupling is weakened, thereby lowering the shocked emission and velocity widths. Reference: Meenakshi et al. 2022, MNRAS, 516, 766. Ref.(Figure 1).

Cosmic Magnetic Fields.

Non-locality of the Turbulent Electromotive Force

The generation of large-scale magnetic fields in astrophysical systems is driven by the mean turbulent electromotive force, the cross correlation between lo-

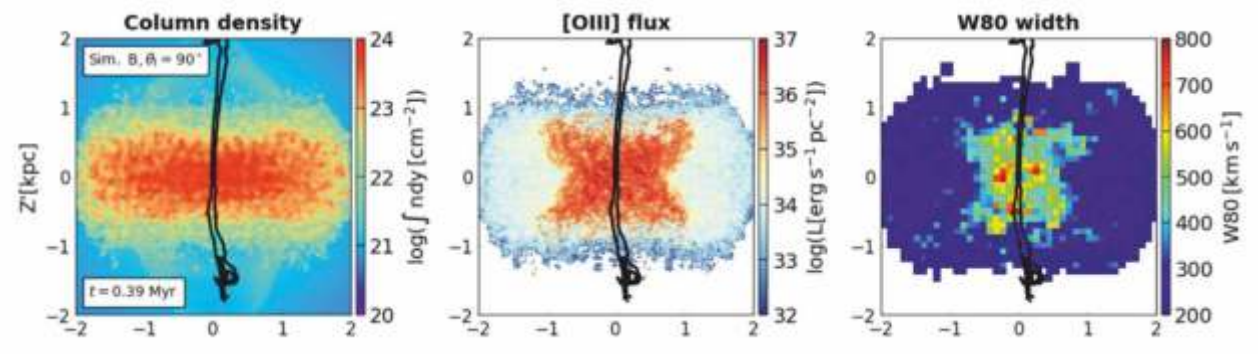


Figure 1: Surface brightness of [OIII] from shocked gas, the associated velocity kinematics of the gas and dispersion, computed from simulations of jet-ISM interactions (Meenakshi et al. 2022).

cal fluctuations of velocity and magnetic fields. This can depend non-locally on mean field through a convolution kernel K_{ij}. In a new approach to find K_{ij}, we directly fit the time series data of mean emf versus the mean field from a galactic dynamo simulation using singular value decomposition. Abhijit Bendre, **Kandaswamy Subramanian** calculate the usual turbulent transport coefficients as moments of K_{ij}, show the importance of including non-locality over eddy length-scales to fully capture their amplitudes and that higher order corrections to the standard transport coefficients are small in the present case.

Magnetic helicity fluxes from triple correlators

Fluxes of the magnetic helicity density play an important role in large-scale turbulent dynamos, allowing the growth of large-scale magnetic fields while overcoming catastrophic quenching. Kishore Gopalakrishnan, **Kandaswamy Subramanian** show analytically, how several important types of magnetic helicity fluxes can arise from terms involving triple correlators of fluctuating fields in the helicity density evolution equation. For this, They assume incompressibility and weak inhomogeneity, and use a quasinormal closure approximation: fourth-order correlators are replaced by products of second-order ones, and the effect of the fourth-order cumulants on the evolution of the third moments is modelled by a strong damping term. First, They show how a diffusive helicity flux, till now only measured in simulations, arises from the triple correlation term. This is accompanied by what They refer to as a 'random advective flux', which predominantly transports magnetic helicity along the gradients of the random fields. They also find that a new helicity flux contribution, in some aspects similar to that first proposed by Vishniac, can arise from the triple correlator. This contribution depends on the gradients of the random magnetic and kinetic energies along the large-scale vorticity, and thus arises in any rotating, stratified system, even if the turbulence is predominantly nonhelical. It can source a large-scale dynamo by itself while spatially transporting magnetic helicity within the system.

Cosmology and Structure Formation

Tabletop potentials for inflation from f(R) gravity

Varun Sahni, Yuri Shtanov and Swagat Mishra have shown that a large class of modified gravity theories (MOG) with the Jordan-frame Lagrangian f(R) translate into scalar-field (scalaron) models with hilltop potentials in the Einstein frame. (A rare exception to this rule is provided by the Starobinsky model for which the corresponding scalaron potential is plateau-like only for positive values of the scalaron.) We find that MOG models featuring two distinct mass scales lead to scalaron potentials that have a flattened hilltop, or tabletop. Inflationary evolution in tabletop models agrees very well with CMB observations. Tabletop potentials therefore provide a new and compelling class of MOG-based inflationary models. By contrast, MOG models with a single mass scale generally correspond to steep hilltop potentials and fail to reproduce the CMB power spectrum. Inflationary evolution in hilltop/tabletop models can proceed in two alternative directions: towards the stable point

at small R describing the observable universe, or towards the asymptotic region at large R. The MOG models which we examine have several new properties including the fact that gravity can become asymptotically vanishing, with Geff→0, at infinite or large finite values of the scalar curvature R. A universe evolving towards the asymptotically vanishing gravity region at large R will either run into a 'Big-Rip' singularity, or inflate eternally.

The phenomenology of the external field effect in cold dark matter models

In general relativity (GR), the internal dynamics of a self-gravitating system under free-fall in an external gravitational field should not depend on the external field strength. Recent work has claimed a statistical detection of an 'external field effect' (EFE) using galaxy rotation curve data. **Aseem Paranjape** and Ravi K. Sheth show that large uncertainties in rotation curve analyses and inaccuracies in published simulation-based external field estimates compromise the significance of the claimed EFE detection. They further show analytically that a qualitatively similar statistical signal is, in fact, expected in a Λ-cold dark matter (ΛCDM) universe without any violation of the strong equivalence principle. Rather, such a signal arises simply because of the inherent correlations between galaxy clustering strength and intrinsic galaxy properties. They explicitly demonstrate the effect in a baryonified mock catalog of a ΛCDM universe. Although the detection of an EFE-like signal is not, by itself, evidence for physics beyond GR, our work shows that the sign of the EFE-like correlation between the external field strength and the shape of the radial acceleration relation can be used to probe new physics: e.g., in MOND, the predicted sign is opposite to that in our ΛCDM mocks.

Lognormal semi-numerical simulations of the Lyman-α forest: comparison with full hydrodynamic simulations

Bhaskar Arya, Tirthankar Roy Choudhury, **Aseem Paranjape**, Prakash Gaikwad study the observations of the Lyman-α (Lyα) forest in spectra of distant quasars which enables them to probe the matter power spectrum at relatively small scales. With several upcoming surveys, it is expected that there will be a many-fold increase in the quantity and quality of data, and hence it is important to develop efficient simulations to forward model these data sets. One such semi-numerical method is based on the assumption that the baryonic densities in the intergalactic medium (IGM) follow a lognormal distribution. In this work, we test the robustness of the lognormal model of the Lyα forest in recovering a set of IGM parameters by comparing with high-resolution Sherwood SPH simulations. We study the recovery of the parameters τ_0 (temperature of the mean-density IGM), γ (slope of the temperature-density relation) and τ_{12} (hydrogen photoionization rate) at z∼2.5 using a Markov Chain Monte Carlo (MCMC) technique for parameter estimation. Using three flux statistics, the probability distribution, the mean flux and the power spectrum, values of all three parameters, τ_0, γ and τ_{12} implied in the SPH simulations are recovered within 1- $\sigma \sim 9,4$ and 1% respectively) of the median (best-fit) values. We verify the validity of our results at different baryon smoothing filter, SNR, box size & resolution, and data seed and confirm that the lognormal model can be used as an efficient tool for modelling the Lyα transmitted flux at z∼2.5.

Bayesian evidence comparison for distance scale estimates

Constraints on cosmological parameters are often distilled from sky surveys by fitting templates to summary statistics of the data that are motivated by a fiducial cosmological model. However, recent work has shown how to estimate the distance scale using templates that are more generic: the basis functions used are not explicitly tied to any one cosmological model. **Aseem Paranjape** and Ravi K. Sheth describe a Bayesian framework for (i) determining how many basis functions to use and (ii) comparing one basis set with another. Our formulation provides intuition into how (a) one's degree of belief in different basis sets, (b) the fact that the choice of priors depends on basis set, and (c) the data set itself, together determine the derived constraints. We illustrate our framework using measurements in simulated datasets before applying it to real data.

Massive neutrino self-interactions and inflation

Certain inflationary models like Natural inflation (NI) and Coleman-Weinberg inflation (CWI) are disfavoured by cosmological data in the standard ΛCDM+r model (where r is the scalar-to-tensor ratio), as these inflationary models predict the regions in the ns-r parameter space that are excluded by the cosmological data at more than 2σ (here ns

is the scalar spectral index). The same is true for single field inflationary models with an inflection point that can account for all or majority of dark matter in the form of PBHs (primordial black holes). Cosmological models incorporating strongly self-interacting neutrinos (with a heavy mediator) are, however, known to prefer lower ns values compared to the ΛCDM model. Considering such neutrino self-interactions can, thus, open up the parameter space to accommodate the above inflationary models. In this work, **Shouvik Roy Choudhury**, Steen Hannestad, Thomas Tram implement the massive neutrino self-interactions with a heavy mediator in two different ways: flavour-universal (among all three neutrinos), and flavour-specific (involving only one neutrino species). They implement the new interaction in both scalar and tensor perturbation equations of neutrinos. Interestingly, They find that the current cosmological data can support the aforementioned inflationary models at 2σ in the presence of such neutrino self-interactions.

Neutrino mass and mass ordering: no conclusive evidence for normal ordering

The extraction of the neutrino mass ordering is one of the major challenges in particle physics and cosmology, not only for its implications for a fundamental theory of mass generation in nature, but also for its decisive role in the scale of future neutrinoless double beta decay experimental searches. It has been recently claimed that current oscillation, beta decay and cosmological limits on the different observables describing the neutrino mass parameter space provide robust decisive Bayesian evidence in favor of the normal ordering of the neutrino mass spectrum. We further investigate these strong claims using a rich and wide phenomenology, with different sampling techniques of the neutrino parameter space. Contrary to the findings of an earlier study, no decisive evidence for the normal mass ordering is found. Neutrino mass ordering analyses must rely on priors and parameterizations that are ordering-agnostic: robust results should be regarded as those in which the preference for the normal neutrino mass ordering is driven exclusively by the data, while Stefano Gariazzo, Martina Gerbino **Shouvik Roy Choudhury**, find a difference of up to a factor of 33 in the Bayes factors among the different priors and parameterizations exploited here. An ordering-agnostic prior would be represented by the case of parameterizations sampling over the two mass-splittings and a mass scale, or those sampling over the individual neutrino masses via normal prior distributions only. In this regard, we show that the current significance in favor of the normal mass ordering should be taken as 2.7σ (i.e. moderate evidence), mostly driven by neutrino oscillation data. Let us stress that, while current data favour the normal mass ordering only mildly, They do not exclude the possibility that this may change in the future. Eventually, upcoming oscillation and cosmological data may (or may not) lead to a more significant exclusion of inverted mass ordering of neutrinos.

Non-parametric Reconstruction of Photon Escape Fraction from Reionization

Non-parametric Reconstruction of Photon Escape Fraction from Reionization: Cosmic reionization is one of the crucial epochs in the evolution of our Universe when neutral hydrogen in the Inter-Galactic Medium got ionized by the ultraviolet (UV) radiation from the first stars. However, not all these ionizing photons can manage to escape into the IGM from their hosting galaxies; only a fraction of it can, and this is known as escape fraction. Although, several theoretical and observational studies have been conducted over the past few years to constrain the escape fraction, no consensus regarding its redshift evolution has yet been achieved. In collaboration with Sourav Mitra, **Atrideb Chatterjee** obtained the first non-parametric reconstruction of this parameter as a function of redshift from a data-driven reionization model using a Gaussian Process Regression method. Our finding suggests a mild redshift evolution of escape fraction with a mean value of 4%,7%,$\sim$ 10% at z=2,6,12. However, a constant escape fraction of 6-10% at z$\geq$6 is still allowed by current data and also matches other reionization-related observations. With the detection of fainter high redshift galaxies from upcoming observations of JWST, the approach presented here will be a robust tool to put the most stringent constraint on escape fraction as well as reionization histories.

Galactic and Extragalactic Astronomy

Host galaxies of ultrastrong Mg II absorbers at $z \sim 0.5$

The Mg II absorption systems with $W_{2796} > 3$Å are known as Ultra-Strong Mg II absorbers (USMgII). They constitute only 0.8% of the Mg II absorber population having $W_{2796} > 0.02$Å. Observationally such

large equivalent widths are seen in a very high fraction (i.e. 30-50%) of (i) outflows detected in z ∼0.5 galaxies; (ii) Milky Way sightlines that probe disk+halo gas; (iii) Galaxy On Top Of Quasars [GOTOQs] and (iv) high-z C I absorbers. It has also been found that more than 50% of USMgII absorbers are damped Lyman-α systems (DLAs; neutral hydrogen column density, $N(\mathrm{HI}) \geq 2 \times 10^{20}\,\mathrm{cm}^{-2}$). It is well known that the measured W_{2796} using low dispersion spectra are related to the number of absorbing clouds and velocity dispersion between them, and not directly related to the column density. For a fully saturated Mg II line, $W_{2796} \geq 3$Å would correspond to a minimum velocity width of 320 $\mathrm{km\,s}^{-1}$. Gas having such velocity spread usually have large metallicities. Large velocity spread could originate from, (i) galactic-scale outflows, (ii) filamentary accretion onto galaxies, (iii) dynamical mergers and intra-group gas. In such cases, measured metallicities and galaxy orientations with respect to the quasar sightlines are used to distinguish between the different possibilities. From a sample of 109 candidate Ultra-Strong Mg II (USMgII; having rest equivalent width of Mg II, $W_{2796} > 3.0$Å) systems at z=0.4-0.6, **Labanya Guha**, **R. Srianand** and their collaborators confirm 27 and identify host galaxies of 20 systems based on associated nebular line emission from their SALT observations or from SDSS fiber spectra (see Figure 2). The measured impact parameter, [O II] luminosity, star formation rate, B-band luminosity and stellar mass are in the ranges $7.3 \leq D[kpc] \leq 79$, $0.2 \leq L_{[O\ II]}[10^{41}\ ergs^{-1}] \leq 4.5$, $2.59 \leq SFR[M_{\odot}yr^{-1}] \leq 33.51$, $0.15L_B^* \leq L_B \leq 1.63L_B^*$ and $10.21 \leq log[M_*/M_{\odot}] \leq 11.62$ respectively. The impact parameters found are larger than that predicted by the W_{2796} vs D relationship of the general population of Mg II absorbers. At a given D, USMgII host galaxies are more luminous and massive compared to typical Mg II absorbers. However, the measured SFRs are slightly lower than that of main-sequence galaxies with same $\mathrm{M}_\star$ at $z \sim 0.5$. They report a correlation between $L_{[O\ II]}$ and W_{2796} for the full population of Mg II absorbers, driven mainly by the host galaxies of weak Mg II absorbers that tend to have low $L_{[O\ II]}$ and large impact parameters. They find at least ∼33% of the USMgII host galaxies (with a limiting magnitude of $m_r < 23.6$) are isolated and the large W_{2796} in these cases may originate from gas flows (infall/outflow) in single halos of massive but not starburst galaxies. They also find galaxy interactions could be responsible for large velocity widths in at least ∼17% cases. This work is part of the thesis of Labanya Guha.

Nature of the galaxies on top of quasars producing Mg II absorption

An efficient way of identifying quasar-galaxy pairs with low impact parameters is to search for nebular emission lines from the foreground galaxies in the SDSS fiber spectra of background quasars [called Galaxies On Top Of Quasar(GOTOQ)]. In the case of GOTOQs, a star-forming foreground galaxy is present within an angular separation of $\sim 1''$ (SDSS DR-12) or $\sim 1.5''$ (SDSS DR-7) and the nebular line emissions from these foreground galaxies are present in the spectra of the background quasar. Without any prior knowledge of the line of sight absorption, just by searching for nebular emission lines (like Hα,[O III], and [O II] from foreground galaxies in the SDSS quasar spectra, a total of 103 GOTOQ were identified in the redshift range $0 \leq z_{abs} \leq 0.84$ in the literature. The alternate approach to identifying the GOTOQs is to search for associated nebular emission lines (e.g., [O II]) in the quasar spectra at the known absorption redshift. Starting from the Mg II$\lambda\lambda\,2796, 2803$ absorption doublet present on the background quasar spectra, if one searches for associated O II$\lambda\lambda\,3727, 3729$ emission which is ubiquitous in all star-forming galaxies, it will allow one to study the disk-halo interface of galaxies over the redshift range $0.35 \leq z \leq 1.5$. Joshi et al. (2018) have identified 198 GOTOQs associated with the Mg II absorbers. The host galaxy properties (in terms of impact parameter distribution, stellar mass, star formation rate, etc.) are not studied in detail till now. The availability of nearly uniform high-quality imaging data from the Dark Energy Spectroscopic Instrument (DESI) Legacy Imaging Survey enables us to undertake such a study. Motivated by this, **Labanya Guha and R. Srianand** studied host galaxies of 198 Mg II absorbers at $0.39 \leq z_{abs} \leq 1.05$ that show detectable nebular emission lines in the SDSS spectra. They report measurements of impact parameter ($5.9 \leq D[kpc] \leq 16.9$) and absolute B-band magnitude ($-18.7 \leq \mathrm{M_B} \leq -22.3$ mag) of host galaxies of 74 of these absorbers using multi-band images from the DESI Legacy Imaging Survey, more than doubling the number of known host galaxies with $D \leq 17$ kpc. This has allowed them to quantify the relationship between Mg II rest equivalent width(W_{2796}) and D, with best fit parameters of $W_{2796}(D = 0) = 3.44 \pm 0.20$Å and an exponential scale length of $21.6^{+2.41}_{-1.97}\ kpc$. The found a significant anti-correlation between M_B and D, and M_B and W_{2796}, consistent with the brighter galaxies producing stronger Mg II absorption. They use stacked images to detect average emissions from

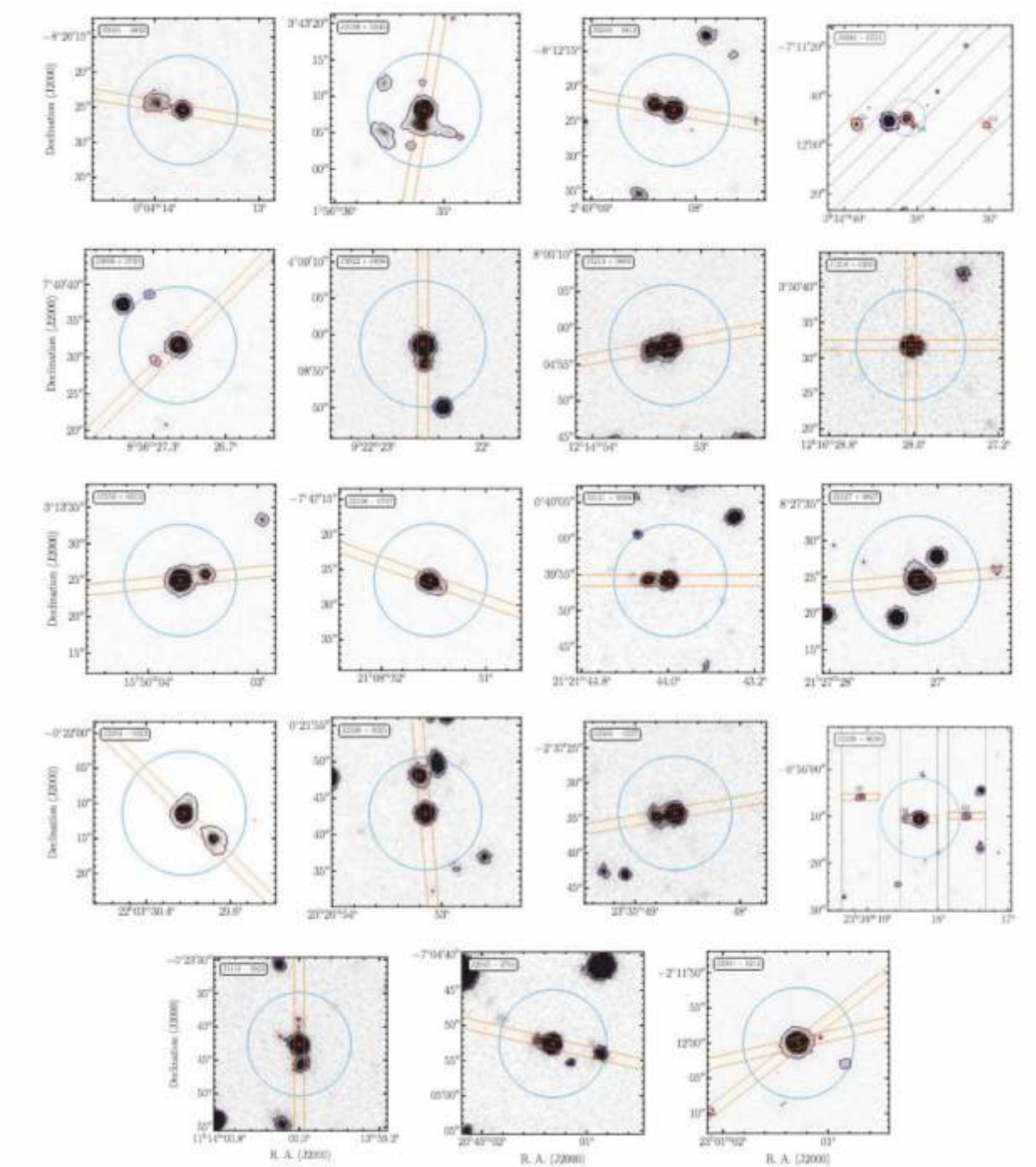


Figure 2: The DECaLS r-band images of the observed USMgII fields by Guha et al. In each of these fields, the quasar sits at the centre and is marked with a red star while in the case of detection, the centre of the associated USMgII host galaxy is marked with a red plus sign. The contours correspond to the 3σ noise level on top of the mean background counts. The blue dashed circle corresponds to the circle with a radius 50 kpc around the quasar. Guha et al's SALT programme aims to obtain redshifts of potential galaxies within 50 kpc. The parallel red dashed line corresponds to the slit of width $1.5''$ used during the SALT observations. For two fields J0334-0711 and J2338-0056 multiple potential galaxies are seen and were targeted using MOS.

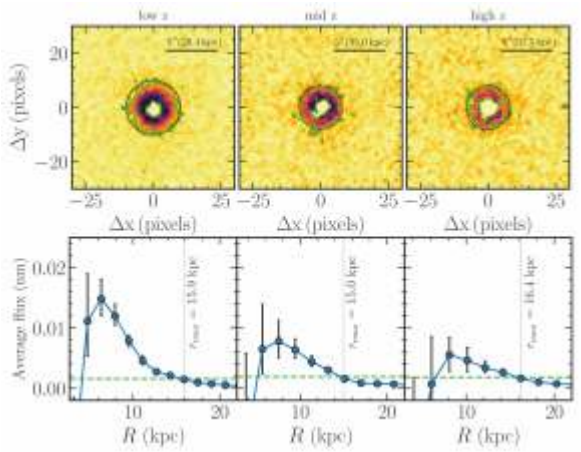


Figure 3: *Top panel:* The r-band stacked images of the GOTOQs in three redshift bins after subtracting the contributions from the QSO and its host galaxy using the control sample of quasars. The $3\sigma_{bgr}$ contours are shown in green. From the left to the right, the three panels correspond to the low-z, mid-z, and high-z bins respectively. *Bottom panel:* The radially averaged flux profiles (in nanomaggy) of the images shown in the top panel as a function of radial distance. The shown errors are obtained using bootstrapping. The green dashed horizontal line corresponds to the $3\sigma_{bgr}$. The solid gray vertical line shows the radial distance where the flux falls below the $3\sigma_{bgr}$. The black circles in the top panel indicate the radius (in the angular scale) corresponding to the r_{max}.

galaxies in the full sample (see Figure 3). Using these images and stacked spectra, we derive the mean stellar mass ($9.4 \leq log(M_*/M_\odot) \leq 9.8$), star formation rate ($2.3 \leq \mathrm{SFR}[M_\odot yr^{-1}] \leq 4.5$), age (2.5−4 Gyr), metallicity (12+log(O/H)∼8.3) and ionization parameter (log q[cm s^{-1}]∼ 7.7) for these galaxies. The average M_* found is less than that of Mg II absorbers studied in the literature. The average SFR and metallicity inferred are consistent with that expected in the main sequence and the known stellar mass-metallicity relation, respectively. High spatial resolution follow-up spectroscopic and imaging observations of this sample are imperative for probing gas flows close to the star-forming regions of high-z galaxies. This work is part of the PhD work of **Labanya Guha.**

Coordinated time variability of multi-phase ultra-fast outflows in J132216.25+052446.3

Among all quasar outflows, ultra-fast AGN outflows (UFOs) are of great interest as they probe the inner regions of the central engine. UFOs are defined as highly ionized absorbers detected mostly through

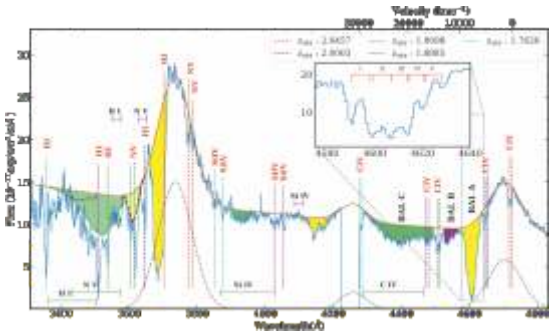


Figure 4: SALT spectrum of J132216.25+052446.3 obtained during MJD 59262 (epoch-9) overlaid with the best fitted continuum (in red). The emission line contributions are shown using dotted Gaussians. The authors mark different absorption lines (identified with labels) from 5 narrow absorption systems identified based on C IV doublets (different colors). For easy discussions, they segregate the C IV broad absorption profile into three components (i.e BAL-A, B and C) shown with shaded regions having different colours. Inset shows the multiple component nature of BAL-A with possible signatures of line-locking at C IV velocity splitting in epoch-2. The velocity scale for C IV BAL absorption with respect to the systemic redshift (z_{em} = 2.0498) is provided at the top. The expected wavelength range for different absorption lines from BAL-B and BAL-C are indicated with magenta and green horizontal lines respectively. In the case of N V and Lyα (both affected by Lyα contamination) the shaded region has been scaled from the C IV profile for illustration.

Fe K shell absorption lines in X-rays at velocities $v_{\mathrm{outflow}} \geq 10^4$ km/s. The high velocities and high ionization state of the absorbers (mainly H-like and He-like Fe) are usually attributed to their origin from within a few hundred gravitational radii from the central black hole where high energy photons are produced. UV absorptions from such broad absorption line (BALs) quasars are commonly observed.
They tend to show larger variability, emergence and acceleration in their BAL profiles. Recently, Rodriguez et al., (2020) have studied a sample of extremely high velocity outflows (EHVO, defined as absorption with outflow velocities between 0.1 and 0.2c). These outflows are detected in 0.6% of quasars searched for C IV absorption. While Lyα associated with the C IV component is either not detected or weak, ∼50% of these BALs show associated N V absorption and about 13% show O VI absorption. These objects tend to have higher black hole mass and bolo-

metric luminosities compared to the general population. Unfortunately, X-ray observations of these high-z EVHOs are not available which makes it difficult to establish any connection between them and X-ray detected UFOs. Possible acceleration mechanisms through which outflows reach such high velocities are still debated. Photon scattering by free electrons alone is not sufficient for the absorbing gas to be accelerated to UFO (or EHVO) velocities. Radiative acceleration through UV line absorption has often been invoked since observational evidences such as line-locking or Ly-α ghost strongly support line-driven BAL outflows. Another alternate mechanism is known as magnetic driving which can also explain highly ionized UFOs. Even though these models are successful in explaining the observed BAL features, they all predict the outflows to be located very close to the central source at a distance of the order of 0.01-0.1 pc. If true, despite carrying large amounts of mechanical energy and momentum, they may have little influence on the large-scale star formation properties of the host galaxy. **P. Aromal, R. Srianand** and Patrick Petitjean of (IAP, Paris) are carrying out a systematic spectroscopic monitoring study of 64 UFOs using SALT. Recently, they presented a time variability analysis of broad absorption lines (BAL; spread over the velocity range of 5800-29000 km/s) seen in the spectrum of J132216.25+052446.3 (z_{em} = 2.04806) at ten different epochs spanning over 19 years. The strongest absorption component (BAL-A; spread over 5800-9900 km/s) is made up of several narrow components having velocity separations close to C IV doublet splitting. The C IV, N V and Si IV absorption from BAL-A show correlated optical depth variability without major changes in the velocity structure (see Figure 4). A very broad and shallow absorption (BAL-C; spread over the velocity range 15000-29000 km/s) emerged during our monitoring period coinciding with a dimming episode of J132216.25+052446.3. All the identified absorption lines show correlated variability with the equivalent widths increasing with decreasing flux. This together with the C IV emission line variability is consistent with ionization being the main driver of the correlated variability. The observed UV-continuum variations are weaker than what is required by the photo-ionization models. This together with a scatter in the C IV equivalent width at a given continuum flux can be understood if variations of the C IV ionizing photons are much larger than that of the UV continuum, the variations in the ionizing photon and UV fluxes are not correlated and/or the covering factor of the flow varies continuously. They suggested BAL-A is produced by a stable clumpy outflow located beyond the broad emission line region and BAL-C is a newly formed wind component located near the accretion disk and both respond to changes in the ionizing continuum. This work is part of the Ph.D. work of P. Aromal.

H I 21-cm absorption in radio-loud AGN with double-peaked [O III] emission

The circumnuclear neutral gas in radio-loud AGN can be probed using H I 21-cm absorption. Associated H I absorption has been used to study: (i) feedback from AGN in the form of neutral gas outflows (which could be induced by radio jets), (ii) cold interstellar medium in the central regions of AGN, and (iii) fueling of AGN (which could be through neutral gas funneled into the central regions due to mergers). If detected, H I 21-cm absorption can be useful to probe the circumnuclear neutral gas at parsec-scales through Very Long Baseline Array (VLBA) spectroscopy. Hundreds of radio-loud AGN have been searched for H I 21-cm absorption till date, with typical detection rates of $\sim 20-30\%$ at $z \leq 0.2$, and lower detection rates ($\leq 10\%$) at higher redshifts. Recently, it has been shown that the incidence of H I 21-cm absorption is elevated in radio-loud AGN that are part of merging systems at $z \leq 0.2$, with a detection rate of $\sim$84%. The significant increase in the incidence and column density of neutral hydrogen gas in such AGN indicate that the merger process is likely to be successful in funnelling large quantities of neutral gas to the central regions of these galaxies and consequently could be playing a role in activating the radio-loud AGN. Different physical processes in galaxy evolution, such as galaxy mergers that lead to coalescence of dual Active Galactic Nuclei (AGN) and outflows emanating from the narrow line region, can leave their imprint on the optical spectra of AGN in the form of double-peaked narrow emission lines. To investigate the neutral gas in the centres of such AGN, Rajeshwari Dutta & **R. Srianand** have conducted a pilot survey of H I 21-cm absorption, using the upgraded Giant Metrewave Radio Telescope (uGMRT), in radio-loud AGN whose optical spectra show double-peaked [O III] emission lines at $z \leq 0.4$ (median $z \sim 0.14$) (see Figure 5). Among the eight sources for which they could obtain clean spectra, they detect H I 21-cm absorption in three sources (detection rate of $38^{+36}_{-20}\%$) and find tentative indication of absorption in two other sources. The detection rate of H I 21-cm absorption is tentatively higher for the systems that show signatures

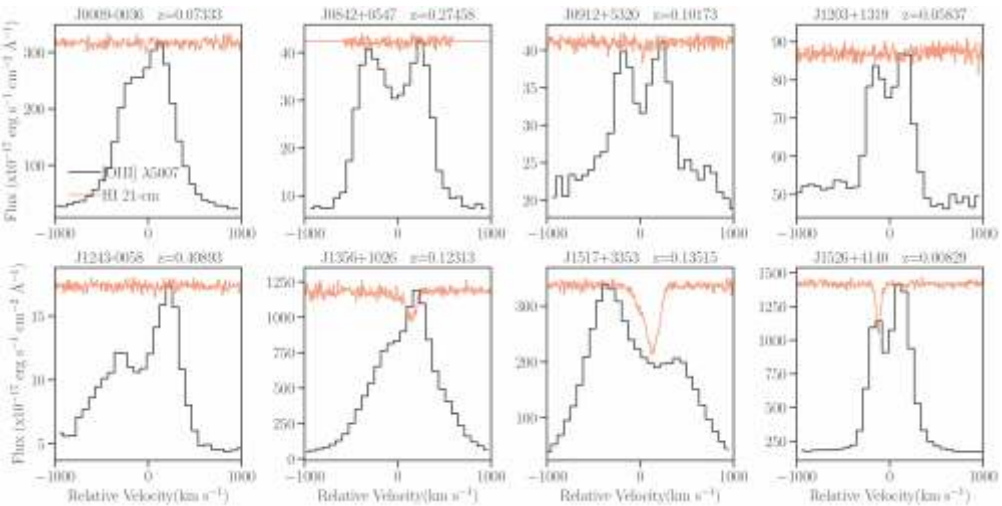


Figure 5: SDSS spectra showing the double-peaked [O III] emission line, of the sources for which they could obtain clean H I 21-cm spectra, are plotted in black. Overplotted in arbitrary flux scale are the H I 21-cm absorption spectra in pink, smoothed to ∼ 8,km/s velocity bins for display purpose. The x-axis is the velocity relative to the redshift given at the top of each panel.

of interaction or tidal disturbance ($\geq$ 50%) in the ground-based optical images than that for the systems that appear single and undisturbed ($\sim$ 25%). This is consistent with the high incidence of H I 21-cm absorption observed in $z \leq 0.2$ galaxy mergers. Higher spatial resolution spectroscopy is required to confirm the origin of the H I absorbing gas, i.e. either gas infalling onto the radio-loud AGN, outflowing gas ejected by the AGN, or gas in rotation on the galactic-scale or circumnuclear discs.

Emergence of a new H I 21-cm absorption component at z ∼1.1726 towards the $\gamma-$ray blazar PKS 2355-106

The H I 21-cm absorption is an excellent probe of cold neutral gas. In the Galaxy, observations of HI 21-cm absorption towards high-velocity pulsars and extended sources have revealed structures in the diffuse interstellar medium [ISM]. These provide important inputs to pressure-equilibrium based models of the ISM. Beyond our Galaxy, such studies are limited to a handful of sight lines towards extended radio sources or gravitationally lensed systems or sources with large proper motions. The scarcity is due to a combination of small number of known H I 21-cm absorbers and paucity of suitable low-frequency receivers for milliarcsecond scale spectroscopy using the Very Long Baseline Interferometry (VLBI). It is anticipated that these limitations will be overcome in near future by ongoing Square Kilometre Array (SKA) precursor surveys and the availability of SKA-VLBI. The variability of extragalactic H I 21-cm absorption lines

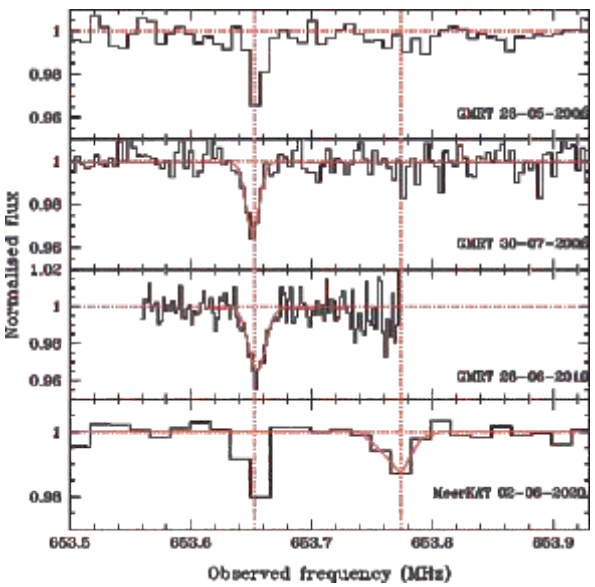


Figure 6: H I 21-cm absorption from the z_{abs} = 1.1730 DLA towards PKS 2355-106 obtained at different epochs, all sharing absorption component-1 at 653.656 GHz. The latest spectrum obtained with MeerKAT shows the additional absorption component-2 at 653.771 MHz. Gaussian fits discussed in the text are shown with red curves.

over the timescales of decades is also relevant for the measurements of variations in fundamental constants of physics and cosmic acceleration. **Srianand** and his collaborators reported the emergence of a new H I 21-cm absorption at $z_{abs} = 1.172635$ in the damped Lyα absorber (DLA) towards the γ-ray blazar PKS 2355-106 (z_{em} ~1.639) using science verification observations (June 2020) from the MeerKAT Absorption Line Survey (MALS). Since 2006, this DLA is known to show a narrow H I 21-cm absorption at $z_{abs} = 1.173019$ coinciding with a distinct metal absorption line component. They do not detect significant H I 21-cm optical depth variations from this known H I component (see Figure 6). A high resolution optical spectrum (August 2010) shows a distinct Mg I absorption at the redshift of the new H I 21-cm absorber. However, this component is not evident in the profiles of singly ionized species. We measure the metallicity ([Zn/H] = $-(0.77\pm0.11)$ and [Si/H]= $-(0.96\pm0.11)$) and depletion ([Fe/Zn] = $-(0.63\pm0.16)$) for the full system. Using the apparent column density profiles of Si II, Fe II and Mg I we show that the depletion and the N(Mg I)/N(Si II) column density ratio systematically vary across the velocity range. The region with high depletion tends to have slightly larger N(Mg I)/N(Si II) ratio. The two HI 21-cm absorbers belong to this velocity range. The emergence of z_{abs} = 1.172635 can be understood if there is a large optical depth gradient over a length scale of ~0.35 pc. However, the gas producing the $z_{abs} = 1.173019$ component must be nearly uniform over the same scale. Systematic uncertainties introduced by the absorption line variability has to be accounted for in experiments measuring the variations of fundamental constants and cosmic acceleration even when the radio emission is apparently compact as in PKS 2355-106.

The three-year shear catalog of the Subaru Hyper Suprime-Cam SSP Survey

The shapes of far away galaxies get distorted due to the gravitational influence of large scale structure in the Universe. These distortions, if measured precisely, can be used to make 3-dimensional maps of dark matter. The correlations of these distortions is also sensitive to the cosmological parameters, such as the matter density parameter and the amplitude of density fluctuations in the Universe. In research work performed by an international team under the leadership of **Surhud More** the shapes of about 35 million galaxies were accurately measured and characterized to enable further cosmological analyses using data from the Wide layer of the Hyper Suprime-Cam (HSC) Subaru Strategic Program (SSP) Survey. The galaxy shapes are measured from the i-band imaging data acquired from 2014 to 2019 and was calibrated with image simulations that resemble the observing conditions of the survey based on training galaxy images from the Hubble Space Telescope in the COSMOS region. The mean i-band seeing which determined how much the atmosphere blurs the galaxy images is merely 0.59 arcsecond. The team defined the requirements for cosmological weak-lensing science for this shear catalog, and quantified potential systematics in the catalog using a series of internal null tests for systematics related to point-spread function modelling and shear estimation. They present a variety of null tests that are statistically consistent with zero or within requirements, but show that (i) there is evidence for PSF model shape residual correlations; and (ii) star-galaxy shape correlations reveal additive systematics. Both effects become significant on larger than 1 degree scales and will require mitigation during the inference of cosmological parameters using cosmic shear measurements.

Subaru HSC weak lensing of SDSS redMaPPer cluster satellite galaxies: empirical upper limit on orphan fractions

Galaxy clusters are collections of galaxies that reside in a very small region of space. At the centers of these clusters one usually find a bright central galaxy. This massive galaxy is surrounded by numerous smaller galaxies called satellites. The satellite galaxies live in a dense environment. How does the dense environment of the cluster affect the properties of these satellite galaxies? Weak gravitational lensing can be used to directly measure the matter distribution surrounding such satellite galaxies. In the study undertaken by **Amit Kumar** along with **Surhud More** and **Divya Rana**, the weak lensing signal induced on the shapes of background galaxies around the Sloan Digital Sky Survey (SDSS) redMaPPer cluster satellite galaxies was measured. They selected clusters with central galaxies assigned with a probability Pcen > 0.95 in the redshift range [0.1,$\leq$ z$\leq$ 0.33]. They used the galaxy shapes from the Subaru Hyper Suprime-Cam (HSC) survey for the purpose of measuring the lensing signal. They binned satellite galaxies by their distance from the cluster centre and compare it to the signal around a control sample of galaxies that do not reside in clusters but have similar colours and magnitudes. They explore the effect of environmental

processes on the dark matter mass around satellites. Their results show hints of a difference in the mass of the subhalo of the satellite compared to the halo masses of galaxies in our control sample, especially in the innermost cluster-centric radial bin ($0.1 < r < 0.3$ [h^{-1} Mpc]). For the first time, this research was able to put an upper limit on the prevalence of orphan galaxies that have entirely lost their dark matter haloes with cluster-centric distances with the help of our measurements and present how much these upper limits might be relaxed if given the expected contamination in the satellite galaxy sample.

The Signatures of Self-interacting Dark Matter and Subhalo Disruption on Cluster Substructure

The abundance, distribution, and inner structure of satellites of galaxy clusters can be sensitive probes of the nature of dark matter. In research work led by a Presidency University masters student (who is now a PhD student at Ohio University), and along with IUCAA members Surhud More and Amit Kumar, they describe a suite of 30 cosmological zoom-in simulations with self-interacting dark matter (SIDM). These self-interactions are assumed to have a velocity-dependent cross section in these simulations. They used these simulations to study the properties of subhalos within cluster-mass hosts, and thus understand the observable effects of the self-interactions. The results show that the abundance of subhalos that survive in the SIDM simulations are suppressed relative to their cold dark matter (CDM) counterparts. Once the population of disrupted subhalos-which may host orphan galaxies-is taken into account, satellite galaxy populations in CDM and SIDM models can be reconciled. However, even in this case, the inner structures of subhalos are significantly different in the two dark matter models. They also study the feasibility of using the weak-lensing signal from the subhalo density profiles to distinguish between the cold and self-interacting dark matter while accounting for the potential contribution of orphan galaxies. Their results show that the effects of self-interactions on the density profile of subhalos can appear degenerate with subhalo disruption in CDM, when orphans are accounted for. With current error bars from the Subaru Hyper Suprime-Cam Strategic Program, we find that subhalos in the outskirts of clusters (where disruption is less prevalent) can be used to constrain dark matter physics. They show that in the future, the Vera C. Rubin Observatory Legacy Survey of Space and Time will give precise measurements of the weak-lensing profile and can be used to constrain σ_T/m at the $\sim 1 cm^2 g^{-1}$ level at a velocity scale of $2000 kms^{-1}$.

The most distant gamma-ray emitting FRII radio galaxy

The orientation of the jet axis to the line of sight of the observer plays a major role in explaining the phenomena observed from blazars and radio galaxies. In the γ-ray band, only a handful of radio galaxies have been identified, all being located in the nearby Universe ($z < 0.5$). **Vaidehi S. Paliya, D. J. Saikia** and C. S. Stalin have reported the identification of 4FGL J1435.5+2021, associated with TXS 1433+205, as a Fanaroff-Riley type II (FR II) radio galaxy at a considerably higher redshift of $z = 0.748$, thereby making it the most distant γ-ray detected radio galaxy known as of now. The Very Large Array Sky Survey data at 3 GHz resolves the source morphology into a bright core, a jet and two hotspots, with a total end-to-end projected length between lobe extremities of ∼0.55 million light years. The optical and radio properties of this enigmatic object suggest it to be a high-excitation FR II radio galaxy. The multiwavelength behaviour of TXS 1433+205 is found to be similar to other γ-ray detected FR II sources but is at the high-luminosity end. They suggest that the ongoing and upcoming high-resolution radio surveys will lead to the identification of many more high-redshift radio galaxies in the γ-ray sky, thus allowing comprehensive studies of misaligned relativistic jets.

Probing the outskirts of galaxy clusters using background quasars

Galaxy clusters are the most massive, gravitationally bound objects in the universe. The galaxies residing inside clusters are embedded in a very hot (>10∧7 K) medium called the intra-cluster medium (ICM). The properties of the ICM, and hence clusters, are well studied via the ample radiation it emits in the X-ray and GHz bands of the electromagnetic spectrum. However, the outskirts of galaxy clusters, where a cluster meets the intergalactic medium (IGM), are not well explored observationally. This is due to the fact that the hot gas in the ICM becomes substantially cooler and diffuse enough to emit any detectable electromagnetic radiation. Being the interface between clusters and the IGM, cluster outskirts act as "melting pots," where infalling metal-poor gas from the IGM mixes with metal-rich gas when galaxies and groups of galaxies are stripped via ram pressure and

tidal forces. Thus, it is a new frontier for understanding gas flows in and around clusters and the environmental processes that drive galaxy evolution in the most massive structures in the universe. In a recent paper (2022ApJ...933..229M), two IUCAA scientists (**Sapna Mishra** and **Sowgat Muzahid**) reported the first-ever detection of cool, metal-enriched gas using a huge sample of galaxy clusters obtained from the Sloan Digital Sky Survey (SDSS) data. They used a technique called quasar absorption line spectroscopy, which is known to be an excellent probe of the gas that does not emit electromagnetic radiation appreciably and is otherwise invisible. They confirmed the detection of a very weak signal in the composite of nearly 80,000 quasar spectra, which will remain undetected in individual spectra. Their findings confirm the presence of a metal-rich gas reservoir surrounding galaxy clusters out to several Mpc from the cores. More recently, in a followup paper, Mishra et al. (2023arXiv230505698M) reported the first statistical detection of cool, neutral hydrogen gas in cluster outskirts using a large spectroscopic dataset obtained from the Hubble Space Telescope (HST). They showed that the chances of detecting neutral hydrogen are significantly lower in cluster outskirts as compared to galactic halos (also known as the circumgalactic medium; CGM) and that the distribution of this gas is patchy. They further showed that the CGM of galaxies residing in cluster outskirts is considerably deficient in neutral gas compared to their field counterparts, which they attributed to environmental processes such as ram pressure and tidal stripping. They showed that such environmental effects are more pronounced for galaxies that are closer to cluster centres or that are in massive clusters.

Jet-induced molecular gas excitation and turbulence in the Teacup

An international team of researchers, including IUCAA scientists **M. Meenakshi** and **Dipanjan Mukherjee** , have found definitive signatures of active jet-ISM interaction through observations of molecular gas in a galaxy known as the "Tea-Cup" galaxy. The authors found enhanced velocity dispersion and higher brightness temperature ratio not only along the jet, but also along directions perpendicular to the jet. The fact that the signatures of interaction of the jet with its ambient gas can be found in locations away from the jet had been predicted in earlier simulations (Mukherjee et al. 2018). The current study confirms this prediction. The results of this study suggest that the radio jet is compressing and accelerating the molecular gas, and driving a lateral outflow that shows enhanced velocity dispersion and higher gas excitation. These results provide further evidence that the coupling between the jet and the ISM is relevant to AGN feedback even in the case of radio-quiet galaxies. Reference: Audibert et al., A&A, 2023, 671, L12. Ref.(Figure 7)

A bar-bell shaped giant radio galaxy with kinks

Pratik Dabhade and collaborators have reported finding a peculiar giant radio galaxy (GRG) J223301+131502 using deep multi-frequency radio observations from GMRT (323, 612, and 1300 MHz) and LOFAR (144 MHz) along with optical spectroscopic observations with the WHT 4.2m optical telescope. Their observations have firmly established its redshift of 0.09956 and unveiled its exceptional jet structure extending more than ∼200 kpc leading to a peculiar kink structure of ∼100 kpc. The overall size of this GRG is ∼6 million light years; it exhibits lobes without any prominent hotspots and closely resembles a barbell. The magnetic field strength of ∼5 μG and spectral ages between about 110 to 200 mega years for the radio lobes were estimated using radio data from LOFAR 144 MHz observations and GMRT 323 and 612 MHz observations. Possible causes leading to the formation of the observed kink feature for the GRG include precession of the jet axis, development of instabilities and magnetic reconnection. Despite its enormous size, the Barbell GRG is found to be residing in a low-mass galaxy cluster, and provides an opportunity to explore the structure and growth of GRGs in different environments.

Jets in radio galaxies and quasars

Jets are the signatures of energy supply from the supermassive black holes in the nuclear regions of active galactic nuclei to form the extended lobes of radio emission which can extend up to about 16 million light years. They can affect the properties of the host galaxies, affecting star formation, and poses a number of challenging astrophysical questions. These include the launching of jets, generation of energy and propagation of jets to such large distances. Our current understanding of jets in radio galaxies and quasars from an observational perspective has been reviewed by **Dhruba J Saikia**.

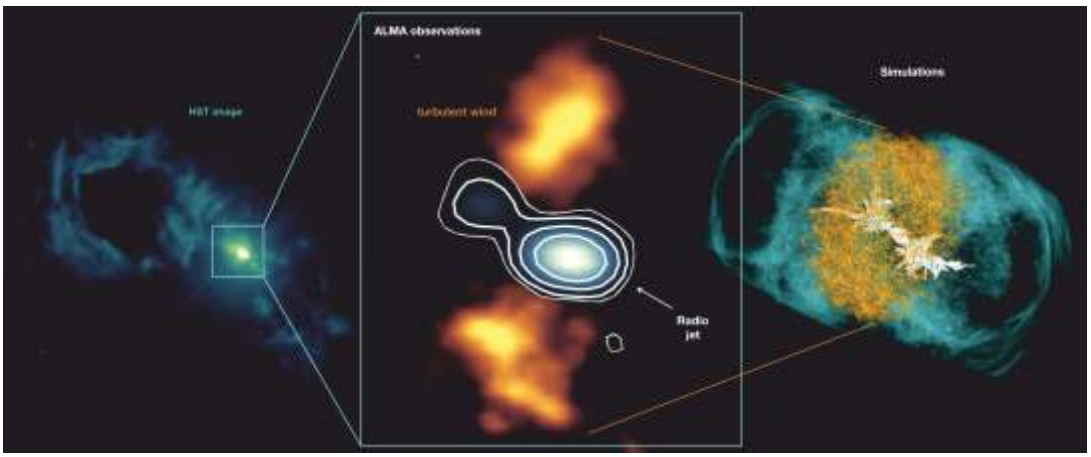


Figure 7: Left: An image of ionised gas in the Tea-Cup galaxy obtained using the Hubble Space Telescope. Middle: Velocity dispersion of the molecular gas in the central region of the Tea-Cup galaxy. The white contours demarcate the location of the radio jet. Right: A 3D volume rendering of the synthetic emission from the relativistic hydrodynamic simulations of jet-ISM interaction. Image credit: A. Audibert, **M. Meenakshi** and **Dipanjan Mukherjee** (url-https://web.iucaa.in/news/JBBTG/)

Giant radio sources

Giant radio sources (GRSs) defined to be larger than about 2.3 million light years are the largest single objects in the Universe and can be associated with both galaxies (GRGs) and quasars (GRQs). They are important for understanding the evolution of radio galaxies and quasars whose sizes range from a few to millions of light years, and are also valuable probes of their environment. These radio-loud active galactic nuclei (RLAGN) interact with the interstellar medium of the host galaxy on small scales and the large-scale intracluster or intergalactic medium for the GRSs. With several new and sensitive surveys over the last few years, the number of known GRSs has increased many fold which has led a resurgence of interest in the field. Pratik Dabhade, **D. J. Saikia** and Mousumi Mahato have reviewed our current understanding of these sources based on nearly five decades of research, and discussed the importance of the Square Kilometer Array (SKA) in addressing some of the outstanding questions.

New insights into giant radio quasars

Giant radio quasars (GRQs) are radio-loud active galactic nuclei (AGN) that propel megaparsec-scale jets. In order to understand GRQs and their properties, Mousumi Mahato and collaborators have compiled all known GRQs ('the GRQ catalogue') and a subset of smaller-sized radio quasars (SRQs) from the literature. They have found ten new Fanaroff-Riley type-II GRQs in the redshift range of $0.66 < z < 1.72$. Using the above samples, they show that the GRQs and SRQs statistically have similar spectral index and black hole mass distributions. However, SRQs have a 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 giant radio galaxies (GRGs), GRQs have a 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 between the accretion disc luminosity and 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 be bi-modal, similar to that found in small radio galaxies (SRGs) and SRQs, which indicates that size is not strongly dependent on the accretion state. Using all of this, they provide a basic model for the growth of SRQs to GRQs.

Gravitational Lensing

Survey of Gravitationally lensed objects in HSC Imaging (SuGOHI). VIII. New galaxy-scale lenses from the HSC SSP :

Anupreeta More and K. C. Wong, J. H. H Chan conducted a search for galaxy-scale strong gravita-

tional lens systems in Data Release 4 of the Hyper Suprime-Cam Subaru Strategic Program (HSC SSP), consisting of data taken up to the S21A semester. About 10300 luminous red galaxies are selected from the Baryon Oscillation Spectroscopic Survey (BOSS) sample that have deep multiband imaging from the HSC SSP and use the YattaLens algorithm to automatically identify lens candidates with blue arc-like features. The candidates are visually inspected and graded based on their likelihood of being a lens. In summarry, 8 definite lenses, 28 probable lenses, and 138 possible lenses are discovered. The new lens candidates generally have lens redshifts in the range $0.3 \leq z_{\rm L} \leq 0.9$, a key intermediate redshift range to study the evolution of galaxy structure. Follow-up spectroscopy will confirm these new lenses and measure source redshifts to enable detailed lens modeling.

Gravitational lensing of gravitational waves: Probability of microlensing in galaxy-scale lens population :

With the increase in the number of observed gravitational wave (GW) signals, detecting strongly lensed GWs by galaxies has become a real possibility. Lens galaxies also contain microlenses (e.g., stars and black holes), introducing further frequency-dependent modulations in the strongly lensed GW signal within the LIGO frequency range. The multiple lensed signals in a given lens system have different underlying macro-magnifications ($|\mu|$) and are located in varied microlens densities ($\Sigma_\bullet$), leading to different levels of microlensing distortions. This work quantifies the fraction of strong lens systems affected by microlensing using realistic mock observations. **Anuj Mishra, Anupreeta More, Sukanta Bose** and collaborators studied 50 quadruply imaged systems (quads) by generating 50 realizations for each lensed signal. However, these conclusions are equally valid for lensed signals in doubly imaged systems (doubles). The lensed signals studied here have $|\mu| \sim [0.5, 10]$ and $\Sigma_\bullet \sim [10, 10^3]$ $\mathrm{M_\odot/pc^2}$. It is found that the microlensing effects are more sensitive to the macro-magnification than the underlying microlens density, even if the latter exceeds 10^3 $\mathrm{M_\odot/pc^2}$. The mismatch between lensed and unlensed GW signals rarely exceeds 1% for nearly all binary black hole sources in the total mass range [10 $\mathrm{M_\odot}$, 200 $\mathrm{M_\odot}$]. This implies that microlensing is not expected to affect the detection or the parameter estimation of such signals and does not pose any further challenges in identifying the different lensed counterparts when macro-magnification is $\leq$10. Such a magnification cut is expected to be satisfied by $\sim$50% of the detectable pairs in quads and $\sim$90% of the doubles in the fourth observing run of the LIGO–Virgo detector network.

Ordering the confusion: a study of the impact of lens models on gravitational-wave strong lensing detection capabilities

When traveling from their source to the observer, gravitational waves can get deflected by massive objects along their travel path. For a massive lens and a good source-lens alignment, the wave undergoes strong lensing, leading to several images with the same frequency evolution. These images are separated in time, magnified, and can undergo an overall phase shift. Searches for strongly-lensed gravitational waves look for events with similar masses, spins and sky location and linked through so-called lensing parameters. However, the agreement between these quantities can also happen by chance. To reduce the overlap between background and foreground, one can include lensing models. When doing realistic searches, one does not know which model is the correct one to be used. Using an incorrect model could lead to the non-detection of genuinely lensed events. In this work, **Anupreeta More** and Justin Janquart, Chris Van Den Broeck investigated how to reduce the false alarm probability when searching for strongly lensed events. The focus is on the impact of the addition of a model for the lens density profile and investigation of the effect of potential errors in the modeling. It is shown that the risks of false alarm are high without the addition of a lens model. It is also shown that slight variations in the profile of the lens model are tolerable, but a model with an incorrect assumption about the underlying lens population causes significant errors in the identification process. Finally, some strategies are suggested to improve confidence in the detection of strongly-lensed gravitational waves.

Deep learning network to distinguish binary black hole signals from short-duration noise transients

Blip glitches, a type of short-duration noise transient in the LIGO–Virgo data, are a nuisance for the binary black hole (BBH) searches. They affect the BBH search sensitivity significantly because their time-domain morphologies are very similar, and that creates difficulty in vetoing them. In this work, **Sunil Choudhary, Anupreeta More, Sudhagar S and**

Sukanta Bose constructed a deep-learning neural network to efficiently distinguish BBH signals from blip glitches. The Sine-Gaussian projection (SGP) maps are introduced, which are projections of GW frequency-domain data snippets on a basis of sine-Gaussians defined by the quality factor and central frequency. The SGP maps are fed to the deep-learning neural network, which classifies the BBH signals and blips. Whereas only simulated BBH signals are used for training, both simulated and real BBH signals are used for testing. For glitches only blips from real LIGO data are used for both testing and training. It is shown that the network significantly improves the identification of the BBH signals in comparison to the results obtained using traditional-χ^2 and sine-Gaussian χ^2. For example, this network improves the sensitivity by 75% at a false-positive probability of 10^{-2} for BBHs with total mass in the range $[80, 140]$ $M_\odot$ and SNR in the range $[3, 8]$. When tested on real GW events, it correctly identifies 95% of the events in GWTC-3. The computation time for classification is a few minutes for thousands of SGP maps on a single core. With further optimisation in the next version of this algorithm, a further reduction in the computational cost is expected. The proposed method can potentially improve the veto process in the LIGO–Virgo GW data analysis and conceivably support identifying GW signals in low-latency pipelines.

STRIDES: automated uniform models for 30 quadruply imaged quasars

Gravitational time delays provide a powerful one step measurement of H0, independent of all other probes. One key ingredient in time delay cosmography are high accuracy lens models. Those are currently expensive to obtain, both, in terms of computing and investigator time (105â^'6 CPU hours and â^$\frac{1}{4}$ 0.5-1 year, respectively). Major improvements in modeling speed are therefore necessary to exploit the large number of lenses that are forecast to be discovered over the current decade. In order to bypass this roadblock, building on the work by Shajib et al. (2019), **Anupreeta More** and collaborators have developed an automated modeling pipeline and applied it to a sample of 30 quadruply imaged quasars and one lensed compact galaxy, observed by the Hubble Space Telescope in multiple bands. This automated pipeline can derive models for 30/31 lenses with few hours of human time and ¡100 CPU hours of computing time for a typical system. For each lens, the measurements of key parameters are provided along with the predictions of magnification as well as time delays for the multiple images. The cosmography-readiness of these models is characterised using the stability of differences in Fermat potential (proportional to time delay) w.r.t. modeling choices. For 10/30 lenses, the models are cosmography or nearly cosmography grade (<3% and 3-5% variations). For 6/30 lenses the models are close to cosmography grade (5-10%). These results are based on informative priors and will need to be confirmed by further analysis. However, they are also likely to improve by extending the pipeline modeling sequence and options. In conclusion, uniform cosmography grade modeling of large strong lens samples is shown to be within reach.

Gear-Up for The Action Replay: Leveraging Lensing For Enhanced Gravitational-Wave Early-Warning

Pre-merger gravitational-wave (GW) sky-localisation of binary neutron star (BNS) and neutron star black hole (NSBH) coalescence events, would enable telescopes to capture precursors and electromagnetic (EM) emissions around the time of the merger. **Shasvath Kapadia** and Collaborators propose a novel astrophysical scenario that could provide earlywarning times of hours to days before coalescence with subarcsecond localisation, provided that these events are gravitationally lensed. The key idea is that if the BNS/NSBH is lensed, then so must the host galaxy identified via the EM counterpart. From the angular separation of the lensed host galaxy images, as well as its redshift and the (foreground) lens redshift, They demonstrate that we can predict the time delays assuming a standard lens model. Encouraged by the non-trivial upper limits on the detection rates of lensed BNS/NSBH mergers that we estimate for upcoming observing runs of the LIGO-Virgo-Kagra and third generation networks, we assess the feasibility and benefits of our method. To that end, we study the effect of limited angular resolution Figure (9) of the telescopes on our ability to predict the time delays.They find that with an angular resolution of 0.0500 arc seconds, we can predict time delays of $>$ 1 day with 1α error-bar of O(hours) at best. They also construct realistic time delay distributions of detectable lensed BNSs/NSBHs to forecast the early-warning times we might expect in the observing scenarios we consider. This work has arXiv identifier: arXiv:2302.02916 and is expected to accepted in the Astrophysical Journal Letters soon.

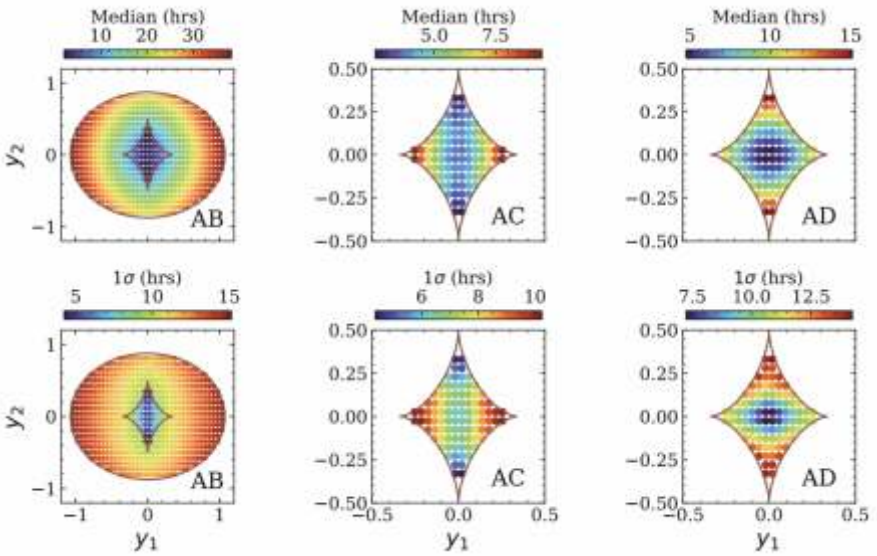


Figure 8: Expected lensed image time delays, and errors in measurement of the time delays, for various source locations in the source plane. The source is a binary neutron star event detectable in the 5th observing run of the LIGO-Virgo network. The lens model is assumed to be the singular isothermal ellipsoid, where either 2 or 4 images are expected. A, B, C, D correspond to the produced images, in the order of their arrival times.

Gravitational Waves

Unmodeled and unresolved distant sources of gravitational waves are expected to create a stochastic background. One can use the cross-correlation between data from pairs of detectors to probe such a background and create a skymap. This process can be computationally expensive. However, the enormous computational efficiency brought by folded data and PyStoch (a pipeline developed primarily at IUCAA, which has became the official pipeline of the LIGO-Virgo-KAGRA (LVK) collaboration to search for anisotropic stochastic backgrounds), not only made broadband mapmaking super-fast, but enabled making sky maps at every frequency bin. The usual broadband search is integrated over all the frequencies, hence it would lose narrowband features or signals present in the data. Moreover, such a search may find potential continuous wave sources, e.g., from mili-second pulsars, which can be followed up by more sensitive, but computationally expensive, matched filtering based searches. The LVK collaboration decided to implement this analysis to make skymaps at every frequency bin - the All-Sky All-Frequency (ASAF) analysis - for O1+O2+O3 data. **Sanjit Mitra** led the analysis, with major contribution from **Deepali Agarwal**, Jishnu Suresh (ICRR, Tokyo) and Anirban Ain (INFN, Pisa). This collaboration paper was made public last year and it was published this year. A set of sample upper limit maps for certain frequencies are shown in the figure. PyStoch development and ASAF analysis are both major achievements led by India and perhaps the first of their kinds, to the extent that PyStoch became the official LVK pipeline for anisotropic SGWB searches and a full collaboration paper was dedicated to the ASAF analysis. (Figure 9)

Hierarchical search strategy in searching for compact binary coalescences

Kanchan Soni, Bhooshan Gadre, **Sanjit Mitra** & **Sanjeev Dhurandhar** One important idea that needs investigation is employing hierarchical search algorithms in gravitational wave searches. Such strategies save in the computational cost in searching for signals, such as, compact coalescing binary stars. Saving on computational cost will free CPU time for searches of other astrophysical sources. Recently an improved detection statistic has been proposed - the phase-time statistic. This statistic has a Bayesian flavour to it, because it incorporates information about the detectors and also on the parameters of the astrophysical sources. We have now employed the hierarchical search strategy to the phase-

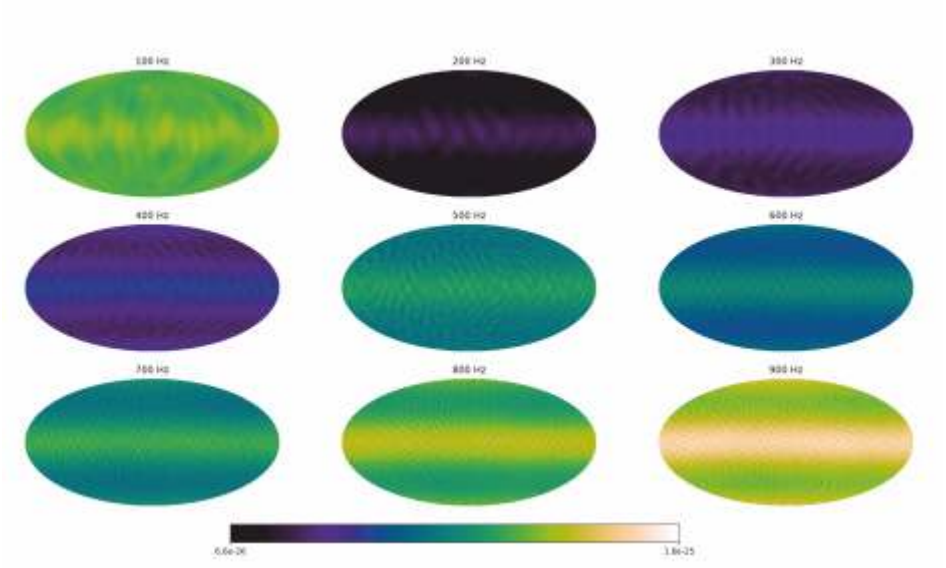


Figure 9: A set of all-sky all-frequency (ASAF) upper limit maps for certain sample frequencies are shown in the figure.

time statistic where we have again obtained a gain factor of about 20. We further expect to contribute a pipeline to the **Ligo software library**, **Kanchan Soni** is the IUCAA student involved in this work under the joint guidance of myself and **Sanjit Mitra**. An important issue here is the statistical significance of detection by the hierarchical method. For this the one must estimate the background noise without losing out too much on the computational gain factor. This work is in progress.

The varied avatars of Time-delay interferometry

M. Tinto, **Sanjeev Dhurandhar** and P. Joshi The space based detector of gravitational waves is the Laser Interferometric Space Antenna (LISA), a joint project of ESA and NASA. Since the space-craft are freely floating, it is by nature an unequal arm interferometer. 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 combines data from the three arms with appropriate delays, so that laser frequency noise is suppressed in a data combination. They have been able to translate this problem as a problem in commutative algebra and algebraic geometry. They have showed that the TDI form a module of syzygies over a polynomial ring. A review article has been published on this in Living Reviews, Springer in 2021. An alternative scheme has been proposed recently using the singular value decomposition to obtain the TDI. This scheme has been termed as TDI-infinity and it has been applied to just two data streams and so is just proof of principle. They have proposed an alternative matrix based scheme for time-delay interferometry. They show that these are just group-theoretic matrix representations of the original TDI which involve abstract operators - we explicitly prove the homomorphism between the two approaches. Our latest work is to map the space of second generation TDI for time-dependent arm-lengths, where we cancel the laser frequency noise upto the first order in velocities. The first generation TDI for which the arm-lengths are time-independent can be solved elegantly in terms of the module of syzygies. The idea is to lift the first generation TDI and then map them to the second generation ones. Prasanna Joshi is a research student currently working for his Ph. D. at Max Planck Institute at Hannover, Germany.

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

Sunil Choudhary, Sukanta Bose, Sanjeev Dhurandhar and P. Joshi The short-duration noise transients in LIGO and Virgo detectors significantly affect the search sensitivity of compact binary coales-

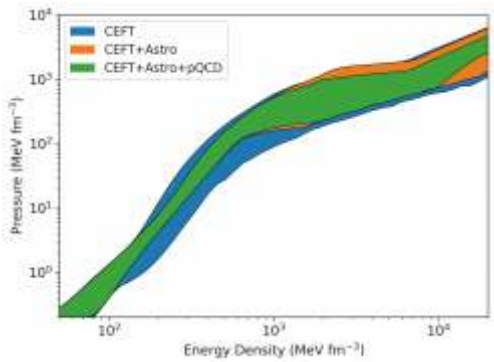
cence (CBC) signals, especially in the high mass region. In the previous work an optimal statistic was proposed to distinguish them from CBCs. This work is an extension of the previous work where **Sunil Choudhary, Sukanta Bose, Sanjeev Dhurandhar** and P. Joshi demonstrate the improved noise-discrimination of the statistic and demonstrate its applicability to real LIGO data. The tuning of the optimal statistic includes accounting for the phase of the CBC signal and a well informed choice of sine-Gaussian basis vectors to discern how CBC signals and some of the most worrisome noise-transients project differently on them. We take real blip glitches (a type of short-duration noise disturbance) from the second observational (O2) run of LIGO-Hanford and LIGO-Livingston detectors. The binary black hole signals were simulated using IMRPhenomPv2 waveform and injected into real LIGO data from the same run. We show that in comparison to the traditional chi square discriminator and other recently proposed discriminators, the optimal discriminator improves the perfomance by about 4 - 5 percent.

Neutron stars - Motivation

Neutron stars (NS), which are the densest objects in the Universe, are effectively cosmic laboratories to probe properties of matter under extreme conditions. In order to describe the complex interior of neutron stars beyond the reach of terrestrial experiments, one must resort to theoretical models involving multi-disciplinary physics (nuclear, particle, condensed matter, general relativity etc) extrapolated to unknown regimes of temperature and density. As the interior NS composition influences its global properties such as mass or radius, comparison with data from multi-wavelength astrophysical observations therefore helps to reduce the model uncertainties. With the recent direct detection of Gravitational Waves, a new window to observe mergers of binary neutron stars has emerged, which reveal crucial information about its ultradense matter. **Debarati Chatterjee** and her research group investigate how the interior composition of neutron stars influences its global properties and gravitational wave emission, and probe properties of dense matter using combined information from theoretical physics, multi-messenger astrophysical data as well as terrestrial experiments (nuclear, hypernuclear and heavy-ion).

Neutron stars -Results

At the ultrahigh densities existing in the core of neutron stars, it is expected that a phase transition from baryonic to deconfined quark matter may occur. Such a phase transition would affect the underlying equation of state (EoS) as well as the observable astrophysical properties of NSs. Comparison of EoS model predictions with astronomical data from multimessen-



ger signals then provides us an opportunity to probe the behaviour of dense matter. In a recent publication (The Astrophysical Journal 944, 2023,7), **Debarati Chatterjee** along with her Ph.D. students **Swarnim Shirke** and **Suprovo Ghosh**, restricted the allowed parameter space of EoS models in NSs for both nucleonic (relativistic mean field model) and quark matter (MIT bag model) sectors by imposing state-of-the-art constraints from nuclear calculations, multimessenger astrophysical data, and perturbative quantum chromodynamics (pQCD). By applying the multiphysics constraints, they significantly reduced the parameter space of the quark model. The study also concluded that astrophysical data disfavours the existence of a pure quark matter core in hybrid stars. Previous studies claimed that there exist correlations among NS global observables and certain nuclear saturation parameters (e.g. the slope of the symmetry energy and the radius of a 1.4 $M_{\odot}$ NS). However, whether such correlations are physical or spurious was not clear, as they are not observed universally for all EoS models. In recent work (Nuclear Physics A 1030, 2023, 122578), **Debarati Chatterjee** along with her Ph.D. student **Bikram K. Pradhan** and collaborators from J.W. Goethe University of Frankfurt, Germany, studied the role of vector self-interaction within the framework of the Relativistic Mean Field model and its role in governing the observable stellar properties and their correlations with nuclear parameters. They showed that the effect of this term is not only to control the high density properties of the EoS but

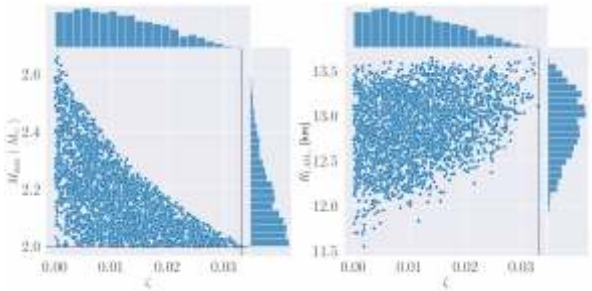


Figure 10: Distribution of vector self-interaction ζ and (a)the maximum mass(left panel)and (b) and the radius of a canonical NS

also in governing such correlations. They also impose a limit on the maximum strength of the vector self-interaction using recent astrophysical data. The r-mode frequencies for slowly rotating Newtonian stars are well known and independent of the equation of state (EoS), but for neutron stars several mechanisms can alter the r-mode frequency for which the relativistic correction is dominant and relevant for most of the neutron stars. The most sensitive searches by GW detectors for continuous GWs are those for known pulsars for which GW frequencies are in targeted narrow frequency bands of a few hertz. In a recent work (The Astrophysical Journal 944, 2023, 53), **Debarati Chatterjee**, along with Ph.D. student **Suprovo Ghosh** and **Dhruv Pathak**, investigated the effect of several state-of-the-art multi-messenger constraints on the r- mode frequency for relativistic, slowly rotating, barotropic stars. They also derived universal relations between r-mode frequency and dimensionless tidal deformability that can be used to estimate the dynamical tide of the r-mode resonant excitation during the inspiral signal. EoS in-

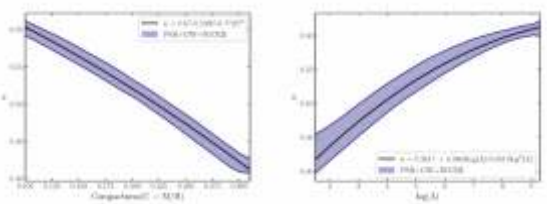


Figure 11: 95%levelther-levelther-mode frequency as a function of compactness (leftpanel) and tidalde formability (rightpanel)for the nonparametric EOS models and the best quadratic model fit.

sensitive relations or universal relations (UR) involving NS global properties play a crucial role in GW astronomy. Considering a wide range of phenomenological EoSs, **Debarati Chatterjee** along with PhD student **Bikram K. Pradhan** and collaborators from ICTS Bangalore updated the EoS-insensitive relations involving NS tidal deformability (multipole Love relation) and the UR between f-mode frequency and tidal deform (Phys. Rev. D 107, 023010), they analysed the binary NS event GW170817 with updated universal relations. In agreement with the literature, they showed that neglecting f-mode dynamical tides can significantly bias the inferred NS properties, especially for low mass NSs. Strong magnetic fields can modify the microscopic composition of NS matter with consequences on stellar macroscopic properties. In a recently published article (Phys. Rev. C 106, 2022, 035801) along with collaborators from Universidade Federale de Santa Catarina, (UFSC, Florianopolis, Brazil) and colleagues from Kent State University (Ohio, USA), Debarati Chatterjee along with PhD student Suprovo Ghosh studied for the first time, the possibility of the appearance of spin-3/2 baryons in magnetars (ultra-magnetised NSs). Using two different models with Δs and hyperons they investigated how their combined effect would influence the structure of magnetars. They found that Δs are favoured over hyperons, and that contrary to expectations they could obtain configurations of massive neutron stars containing Δ particles which match modern observational data. This is not a trivial result, as normally the presence of exotic particles makes the star more compressible and supports lower mass. They also found that the Δ baryons do not have a strong influence on the field configuration, but their presence shrinks stellar radii.

Waltzing Binaries: Probing Line-of-Sight Acceleration of Merging Compact Objects With Gravitational Waves

Line-of-sight acceleration of a compact binary coalescence (CBC) event would modulate the shape of the gravitational waves (GWs) it produces with respect to the corresponding non-accelerated CBC. Such modulations could be indicative of its astrophysical environment. We investigate the prospects of detecting this acceleration in future observing runs of the LIGO-Virgo-KAGRA network, as well as in next-generation (XG) detectors and the proposed DECIGO. We place the first observational constraints on this acceleration, for putative binary neutron star mergers GW170817 and GW190425. We find no evidence of line-of-sight acceleration in these events at 90% confidence. Prospective constraints for the fifth observing run of the LIGO at A+ sensitivity, suggest that accelerations

for typical BNSs could be constrained with a precision of $a/c \sim 10^{-7}$ [s^{-1}], assuming a signal-to-noise ratio of 10. These improve to $a/c \sim 10^{-9}$ [s^{-1}] in XG detectors, and $a/c \sim 10^{-16}$ [s^{-1}] in DECIGO. We also interpret these constraints in the context of mergers around supermassive black holes Figure (12). The arXiv identifier for the paper is: arXiv:2302.09651. It is also expected to be accepted in the Astrophysical Journal as a regular article soon.

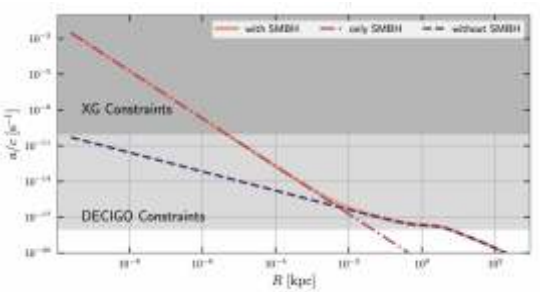


Figure 12: Accelerations in the Milky Way at different distances from its central supermassive black hole (SMBH). The constraints in the figure assume that the acceleration is completely aligned with the line-of-sight, and thus represent a lower limit on the constraints. The dash-dotted and dashed lines respectively show accelerations only assuming the Kepler potential and `MWPotential2014`. Shaded regions showing constraints obtainable by future detector networks are shown for reference.

Shasvath Kapadia has also mentored students at ICTS-TIFR as a continuation of projects that he had begun when he was a Simons prize postdoc there. The projects have resulted in publications in the last year. These include: a project that uses very many gravitational lensed gravitational wave events to infer cosmological parameters (arXiv:2211.12212), one that explores the prospects of detecting continuous gravitational waves from spinning neutron stars lensed by the Galactic supermassive black hole (arXiv:2205.00022, published in Astrophysical Journal Letters), one that exploits gravitational lensing to make unambiguous associations of fast radio bursts with compact binary coalescence events (arXiv:2304.02879), and one that uses Machine Learning to search for signatures of eccentricity in gravitational waveforms pertaining to merging compact objects (arXiv:2302.00666)

Effect of calibration uncertainties on the searches for isotropic gravitational-wave backgrounds

With the improvements in the current gravitational detectors' sensitivities, the detection of gravitational-wave background (GWB) is expected in the near future. The detection and inferences we draw from the searches for GWB will depend on the source model, the type of search pipeline used, and the data generation in the gravitational-wave detectors. In this work, **Shivaraj Kandhasamy**, along with Junaid Yousuf of the University of Kashmir, looked at the effects of the data generation process, specifically the effect of calibration uncertainties on the searches for isotropic GWB. They found that for calibration uncertainties $\lesssim 10\%$, the detection of GWB is not significantly affected. On the other hand, they found that the parameter estimation and upper limit estimates of GWB get biased and need to be considered when trying to differentiate between different models of isotropic GWBs.

High Energy Astrophysics

G. C. Dewangan, performed AstroSat Target of Opportunity observations of a rare, cosmological tidal disruption event (TDE) AT2022cmc at a redshift of 1.193. Many other telescopes around the globe observed this TDE. The findings, published in Nature Astronomy (Pasham et al., including **G. C. Dewangan** and **Priyanka Rani** revealed a black hole that launched a powerful relativistic jet after it tidally disrupts a star. The TDE's unusual X-ray properties, including a peak, observed luminosity that was more than 10∧15 times Sun's luminosity, systematic variability on timescales as short as 1000 seconds and overall duration lasting more than 30 days in the rest frame, are traits associated with relativistic tidal disruption events. The jet launched by the TDE is inferred to align with our line of sight. Hence the overall brightness was Doppler boosted by several orders of magnitude. Subhashree Swain, a Ph.D. student from Pondicherry University, collaborated with **G. C. Dewangan** and **Prakash Tripathi** and K. V. P. Latha (Pondicherry University) and P. Shalima (Manipal University) performed a multiwavelength study of the active nucleus and the off-nuclear X-ray sources in the nearby spiral galaxy, NGC 1365 using three simultaneous UV/X-ray observations by AstroSat over two months and archival IR observations performed

with Spitzer and Herschel. Utilising the Soft X-ray Telescope (SXT) data onboard AstroSat, the team found spectral variability mainly caused by the variation in the X-ray column density. Multiwavelength IR/UV/X-ray AGN SED revealed that the AGN is in a low-luminosity phase. The steady UV emission and substantial X-ray absorption variability suggest that the obscuring clouds are likely compact, affect the compact X-ray source only, and do not cover the extended UV emitting region. The team also identified UV counterparts to four Chandra-identified bright X-ray sources. One well-known ultra-luminous X-ray source (ULX) X2 in NGC1365, is identified with its UV counterpart. Collaborative research between IUCAA (**Gulab Dewangan, Kavita Kumari and Dipankar Bhattacharya**) and the University of Southampton (Ian McHardy and Max Beard) and other collaborators utilised the simultaneous XMM-Newton, Swit and AstroSat observations of a Seyfert 1 galaxy NGC4593 and X-ray to optical, near and far UV time lag spectrum. The team showed that the lag spectrum is entirely consistent with the lags caused by reprocessing of X-rays into optical and UV by the accretion disk. Aditya Sow Mondal, B. Raychaudhri from Visva-Bharti, **G. C. Dewangan** from IUCAA and Aru Beri from IISER, Mohali studied nearly simultaneous NICER and NuSTAR observations of an X-ray transient XTE J1739-285. These observations provided the neutron star X-ray transient's first sensitive hard X-ray spectrum. The source was observed on 2020 February 19 in the hard spectral state with a luminosity of 0.007 of the Eddington limit. The broadband 1-70 keV NICER and NuSTAR observation clearly detected a cutoff of the hard spectral component around 34-40 keV when the continuum is fitted by a soft thermal component and a hard power-law component. This feature has been detected for the first time in this source. The spectrum showed evidence for disc reflection - a relativistically broadened Fe line around 5-8 keV and a Compton hump in the 10-20 keV energy band. The accretion disc reflection features had not been identified before from this source. Through accretion disc reflection modeling, the researchers found a small radius for the inner accretion disk and obtained an upper limit of 6.2e8 G for the magnetic field at the poles.

Vaidehi Paliya studies the gamma-ray emissions which carry the imprint of the extreme and highly energetic astrophysical environments they originate from. Some of the strong gamma-ray emitters in the high-energy sky are active galaxies that launch the collimated outflow of plasma shooting out from their centers, the so-called relativistic jets. The high-energy radiation provides crucial observational information about the behavior of matter and energy in the close vicinity of the central supermassive black hole which is thought to be responsible for the launching of these jets. The galaxies that host jets pointed directly toward Earth are called blazars and those with off-axis jets are termed radio galaxies. The peculiar alignment of jets in blazars dramatically amplifies the radiation because of Doppler boosting thereby making them extraordinarily bright even at cosmological distances. The orientation of the jet axis to the line of sight of the observer plays a major role in explaining the phenomena observed from blazars and radio galaxies. In the gamma-ray band, only a handful of radio galaxies have been identified, all being located in the nearby Universe (redshift $z<0.5$) whereas blazars are discovered up to in the very far universe ($z>4$). A systematic search for the distant gamma-ray emitting radio galaxies by **Vaidehi Paliya** using the latest radio survey data has led to the identification of a radio galaxy, TXS 1433∓205, at a considerably higher redshift of $z = 0.748$, thereby making it the most distant gamma-ray detected radio galaxy known as of now. The Very Large Array Sky Survey data at 3 GHz resolves the source morphology into a bright core, a jet, and two hotspots, with a total end-to-end projected length between lobe extremities of ∼170 kpc (13). The optical and radio properties of this enigmatic object suggest it to be a high-excitation Fanaroff-Riley type II (FR II) radio galaxy. The multiwavelength behavior of TXS 1433∓205 is found to be similar to other gamma-ray detected FR II sources but is at the high-luminosity end. This discovery has strengthened the idea that the ongoing and upcoming high-resolution radio surveys will lead to the identification of many more high-redshift radio galaxies in the gamma-ray sky, thus allowing comprehensive studies of misaligned relativistic jets.

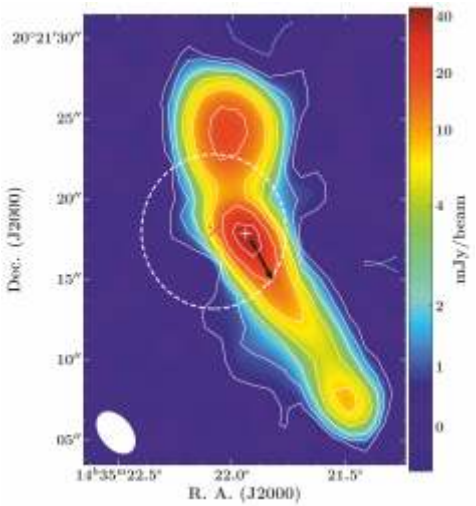


Figure 13: VLASS (3 GHz) image of TXS 1433+205. The rms is 0.17 mJy per beam and the contours are 3×rms×(-1, 1, 2, 4, 8, 16, 32, 64). The 'X' mark represents the X-ray core position measured by Swift-X-Ray Telescope and the dashed circle refers to the uncertainty in the optimized position at 90% confidence. The ∓ mark shows the VLBI core position and the black arrow highlights the direction of the boosted jet. North is up and east to the left.

Instrumentation for Astronomy

A Bose horn antenna radio telescope (BHARAT) design for 21 cm hydrogen line experiments for radio astronomy teaching.

This pedagogical paper, coauthored by **Ashish Mhaske**, Joydeep Bagchi, B.C. Joshi, Joe Jacob, and K.T. Paul was showcased in the December 2022 issue of the American Journal of Physics. A horn antenna setup is low-cost but effective for galactic HI line detection. Except for the horn, all the components are available off the shelf for easy assembly. The setup is designed to be replicated in colleges and universities for HI line experiments. It can be part of their curriculum as a radio astronomy experiment. Hydrogen is the most abundant element in the universe. Neutral atomic hydrogen has a transition line at 1420.405751 Mhz, which falls in the radio wavelength band. Hence, a radio telescope can be used to detect the line. One can do interesting astrophysics with the observations from the instrument described in the paper.

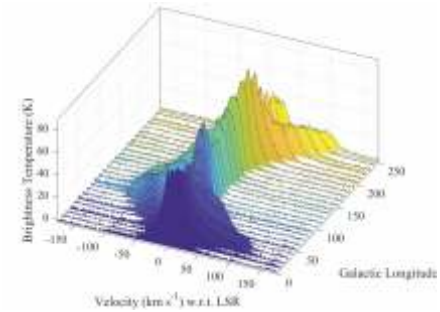


Figure 14: All observations taken for Galactic longitudes (L)—- at intervals of 10

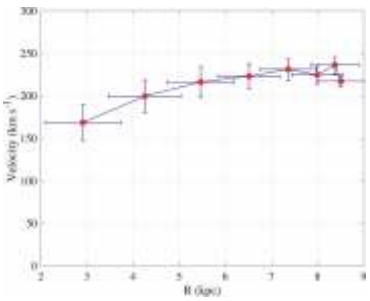


Figure 15: The rotation speed of the Milky Way galaxy obtained as a function of distance R from the galactic center, from our observations. The Sun is located at about 8.5kpc from the center of our Galaxy. A flat rotation curve is observed at this radius with an average rotation speed of 218km/s. This graph proves that our Galaxy is rotating but also that it rotates differentially, not as a solid body but more like a fluid. From such curves, astronomers can infer the presence of mysterious dark matter in spiral galaxies.

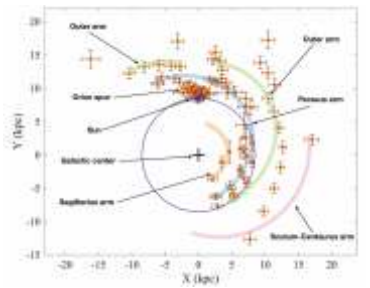


Figure 16: The structure of the Milky Way galaxy obtained using our hydrogen line observations. The blue star represents the Sun, and the blue circle is the solar orbit in the galaxy. Each point represents one peak of an observation. The spiral arms of the galaxy (plotted in color) can be seen distinctly.

Solar Astrophysics

Inferring magnetic helicity spectrum in spherical domains: the method and example applications

Magnetic helicity, which characterises the linkage of field lines, is a topological invariant. In ideal magnetohydrodynamics (MHD) magnetic helicity is conserved, and it is nearly conserved in the limit of large conductivity, a regime which is relevant in astrophysical scenarios. Thus, magnetic helicity imposes a crucial constraint on the evolution of magnetic fields. In the case of the Sun, magnetic helicity is often invoked to investigate many facets of the solar magnetic field. Obtaining observational constraints on the role of turbulent effects for the solar dynamo is a difficult, yet crucial, task. Without such knowledge, the full picture of the operation mechanism of the solar dynamo cannot be formed. In this paper (published in Astronomy & Astrophysics), Nishant Singh and his collaborators demonstrated a formalism in spherical geometry to infer magnetic helicity spectra directly from observations of the magnetic field, taking into account the sign change of magnetic helicity across the Sun's equator. This makes it possible to infer magnetic helicity in spherical geometry, without the necessity of computing the magnetic vector potential. This has the advantage of being gauge invariant. It has many applications in solar and stellar observations, but can also be used to analyze global magnetoconvection models of stars and compare them with observations.

On Strengthening of the Solar f-mode Prior to Active Region Emergence Using the Fourier-Hankel Analysis

Finding ways to reliably predict the emergence of active regions is an important application of solar physics, as it allows for the ability to forecast some aspects of space weather. In an earlier study, **Nishant Singh** et al. (2016) showed that the emergence of an active region (AR) can be seen in a strengthening of the f-mode up to two days prior of the region's formation. This makes the f-mode an attracting candidate which can be used for predicting the occurrences of ARs which ultimately govern the space weather. In this new study (under review in Solar Physics), **Nishant Singh** and his collaborators made use of the Fourier-Hankel method, to essentially test the aforementioned results with an independent method. By investigating the total power as a function of time, they found a similar behavior to the original work, which is an enhancement of f-mode power about one to three days prior to AR emergence.

Shell model for stratified convection: implications for the solar convective conundrum

In this work, IUCAA PhD student **Kishore Gopalakrishnan** and **Nishant Singh** extended the notion of a shell model to stratified systems, and proposed one that represents stratified, nonmagnetic, nonrotating convection at low Mach number. Motivated by profiles of background stratification that support convection in stars such as the Sun, numerical solutions corresponding to a highly unstable layer above a mildly unstable layer were studied. It was found that at low Prandtl number, convective amplitudes decrease with depth in the lower layer. This suggests that the suppression of convection in the deeper layers of the Sun's convection zone (the convective conundrum) can be addressed without necessarily appealing to rotation or magnetic fields.

(Sun and stars) Turbulent Prandtl number from isotropically forced turbulence

Turbulent motions enhance the diffusion of large-scale flows and temperature gradients. Such diffusion is often parameterized by coefficients of turbulent viscosity and turbulent thermal diffusivity that are analogous to their microscopic counterparts. In this work the turbulent diffusion coefficients were computed by imposing sinusoidal large-scale velocity and temperature gradients on a turbulent flow and measuring the response of the system. These results were confirmed using experiments where the imposed gradients are allowed to decay. To achieve this, weakly compressible three-dimensional hydrodynamic simulations of isotropically forced homogeneous turbulence were performed. In this study (published in the Journal of Fluid Mechanics, Rapids) **Nishant Singh** with his collaborator Dr Petri Käpylä found that the turbulent viscosity and thermal diffusion, as well as their ratio, the turbulent Prandtl number, approach asymptotic values at sufficiently high Reynolds and Peclet numbers. No significant dependence of turbulent Prandtl number on the microscopic Prandtl number was seen. These findings are in stark contrast to results from the so-called k-epsilon model. The current results are relevant for the ongoing debate on,

for example, the nature of the turbulent flows in the very-low-Prandtl number regimes of stellar convection zones.

(Cosmic rays): Acceleration of cosmic rays in presence of magnetohydrodynamic fluctuations at small scales

Evolution of the distribution of charged particles (cosmic rays) due to the mechanism of stochastic turbulent acceleration (STA) in presence of small-scale turbulence with a mean magnetic field was explored in this work. STA is usually modelled as a biased random walk process in the momentum space of the non-thermal particles. This results in an advection-diffusion type transport equation for the non-thermal particle distribution function. In this work under quasilinear approximation, Prof Singh with his collaborators found universal scalings for the Fokker-Planck diffusion coefficients as functions of the Lorentz factor. Furthermore, with the calculated transport coefficients, the advection-diffusion type transport equation was numerically solved for the non-thermal particles. Interplay of various mircophysical processes such as STA, synchrotron loss and particle escape on the particle distribution were investigated by systematically varying the parameters of the problem.

(dynamos): Mean-field dynamo due to fluctuating turbulent diffusivity

In systems where the standard α-effect is inoperative, one often explains the existence of mean magnetic fields by invoking the 'incoherent α effect', which appeals to fluctuations of the mean kinetic helicity. Previous studies, while considering fluctuations in the mean kinetic helicity, treated the mean turbulent kinetic energy as a constant, despite the fact that both these quantities involve second-order velocity correlations. The mean turbulent kinetic energy causes both turbulent diffusion and diamagnetic pumping of the mean magnetic field. In this work **Kishore Gopalakrishnan** and **Nishant Singh** use a double-averaging procedure to analytically show that fluctuations of the mean turbulent kinetic energy (giving rise to η-fluctuations, where η is the turbulent diffusivity) can lead to the growth of a large-scale magnetic field even when the kinetic helicity is zero pointwise. These fluctuations tend to reduce the overall turbulent diffusion. It was also found that the diamagnetic pumping, which arises due to inhomogeneities in the turbulent kinetic energy, leads to growing mean field solutions even when the η-fluctuations are isotropic. Our results suggest that fluctuations of the turbulent kinetic energy may be relevant in astrophysical contexts.

Influence of Thomson Electron Scattering Redistribution on Spectral Line Polarization Formed in Spherically Symmetric Extended and Expanding Atmospheres

Early-type hot stars are known to possess highly extended as well as expanding atmospheres. In these stars, electron scattering is one of the main sources of opacity and is known to significantly affect the spectral line wings. Extended atmospheres can be represented by a spherically symmetric medium, as the first approximation. The influence of non-coherent electron scattering (NCES) has been extensively investigated in the case of un-polarized transfer in expanding spherical atmospheres. As for the polarized line transfer, the effect of NCES has been studied mainly in the case of planar static atmospheres. However, On the other hand, the influence of NCES on polarized line profiles formed in spherically symmetric static or expanding atmospheres remains sparsely explored. Here, **Megha Anand** with her collaborator consider intrinsically polarized lines and the problem of polarized spectral line transfer in extended and expanding spherically symmetric atmospheres including the influence of NCES. To explore in detail the influence of NCES on polarized line profiles formed in a spherically symmetric isothermal atmosphere characterized by a frequency-averaged total radial line optical thickness T and outer radius R, **Megha Anand** and collaborators consider the inverse square law opacity distribution for continuum and the spectral lines including the electron scattering opacities. The influence of NCES on line polarization emerging from a spherically symmetric static medium of different outer radius R is shown in Figure 17. The NCES exhibits its influence predominantly in the near and far wings. For a given optical thickness, this bulge, however, decreases as the outer radius R increases and the bulge in the intensity profile is non-existent for $R = 200$. This is because when R is increased keeping the T and other atmospheric parameters fixed, the medium becomes more and more dilute such that the line photons escape after only a few number of scatterings. As for the Stokes Q/I profiles, the influence of NCES is seen for all the different R considered here. Clearly, linear polarization profiles are more sensitive to NCES than intensity profiles. In particular, the intensity in

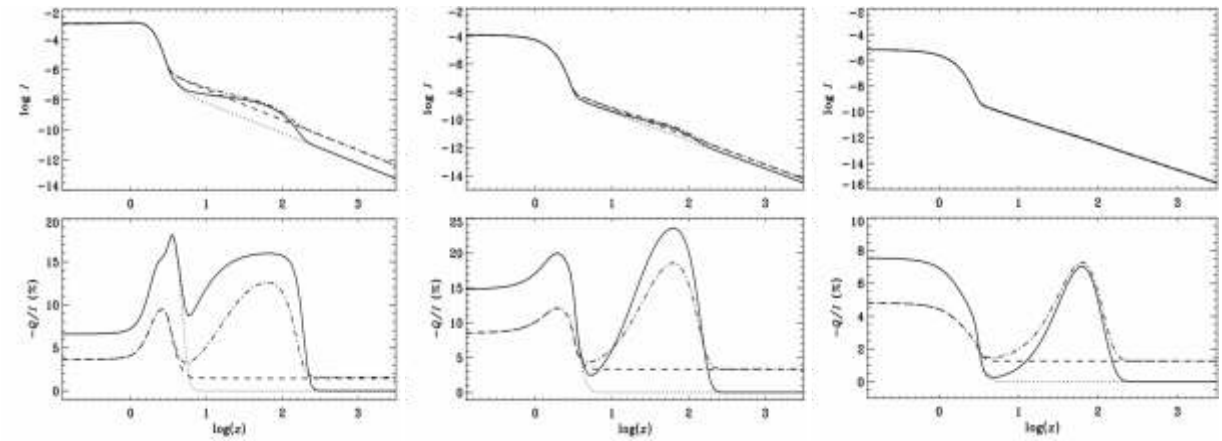


Figure 17: The emergent I and Q/I profiles from a spherically symmetric static medium of outer radius $R = 2$, 20, 200 (panels (a), (b), and (c)). The line-of-sight is at $\mu = 0.1$. NCES is neglected for dotted and dashed lines, while it is included for solid and dot-dashed lines. Here x is the non-dimensional frequency in the units of Doppler width.

the wings is raised in the presence of electron scattering, while a noticeable secondary peak is produced in the Q/I profiles. These numerical results clearly demonstrate the importance of including NCES in spectral line polarization problems relevant to stellar atmospheres.

Global Geomagnetic Perturbation Forecasting Using Deep Learning

Reference: Upendran et al. 2023, Space Weather
Paper link: urlhttps://agupubs.onlinelibrary.wiley.com /doi/10.1029/2022SW003045.
Geo-magnetically Induced Currents (GICs) arise from spatio-temporal changes to Earth's magnetic field, which arise from the interaction of the solar wind with Earth's magnetosphere, and drive catastrophic destruction to our technologically dependent society. Hence, computational models to forecast GICs globally with large forecast horizon, high spatial resolution and temporal cadence are of increasing importance to perform prompt necessary mitigation. Since GIC data is proprietary, the time variability of the horizontal component of the magnetic field perturbation (dB/dt) is used as a proxy for GICs. In this work, **Vishal Upendran** and collaborators develop a fast, global dB/dt forecasting model, which forecasts 30 min into the future using only solar wind measurements as input. The model summarizes 2 hr of solar wind measurement using a Gated Recurrent Unit and generates forecasts of coefficients that are folded with a spherical harmonic basis to enable global forecasts. When deployed, our model produces results in under a second, and generates global forecasts for horizontal magnetic perturbation components at a cadence of 1 min. We evaluate our model across the other existing models in the literature for two specific storms of 5 August 2011 and 17 March 2015, while having a self-consistent benchmark model set. Our model outperforms, or has consistent performance with state-of-the-practice high time cadence local and low time cadence global models, while also outperforming/having comparable performance with the benchmark models. Such quick inferences at high temporal cadence and arbitrary spatial resolutions may ultimately enable accurate forewarning of dB/dt for any place on Earth, resulting in precautionary measures to be taken in an informed manner. An example perturbation forecast is shown in Fig. 18.

Nanoflare Heating of the Quiet Sun Corona Observed in X-Rays

Reference: Upendran et al., 2022 ApJL 940 L38
Paper link: url https://iopscience.iop.org/article /10.3847/2041-8213/aca078 The existence of the million-degree corona above the cooler photosphere is an unsolved problem in astrophysics. Detailed study of the quiescent corona that exists regardless of the phase of the solar cycle may provide fruitful hints toward resolving this conundrum. However, the properties of heating mechanisms can be obtained only statistically in these regions due to their unresolved nature. In this work **Vishal Uepndrana and Durgesh Tripathi** with collaborators we develop a two-step inversion scheme based on the machine-

learning scheme of Upendran & Tripathi (2021a) for the empirical impulsive heating model of Pauluhn & Solanki (2007), and apply it to disk integrated flux measurements of the quiet corona as measured by the X-ray solar monitor on board Chandrayaan–2. We use data in three energy passbands, viz, 1–1.3, 1.3–2.3, and 1–2.3 keV, and estimate the typical impulsive event frequencies, timescales, amplitudes, and the distribution of amplitudes. We find that the impulsive events occur at a frequency of ≈ 25 events per minute with a typical lifetime of ≈ 10 minutes. They are characterized by a power-law distribution with a slope $\alpha \leq 2.0$. The typical amplitudes of these events lie in an energy range of 10^{21}–10^{24} erg, with a typical radiative loss of about $\approx 10^3$ erg

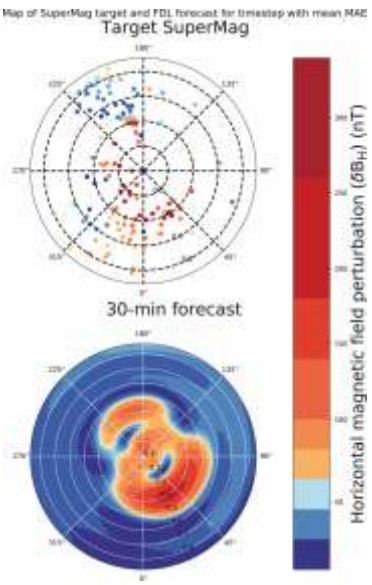


Figure 18: A sample forecast of the horizontal component of the global geomagnetic perturbation field (bottom) compared with the measured perturbation (top) at stations across the globe.

cm^{-2} s^{-1} in the energy range of 1–2.3 keV. These results provide further constraints on the properties of subpixel impulsive events in maintaining the quiet solar corona. A comparison of the observations and ML-based inference of parameter set and generated light curves is shown in Fig. 19.

Center to limb variation of transition region Doppler shift in active regions

Reference: Abhishek Rajhans et al 2023 ApJ 944 158
Paper link: `https://iopscience.iop.org/article/10.3847/1538-4357/acb4ed`

Studying Doppler shifts provides deeper insights into the flow of mass and energy in the solar atmosphere. Persistent downflows have been observed in the transition regions of the active regions. This was explained by Antiochos(1984) as a signature of field-aligned flows due to condensation. Moreover, to account for the absence of CLV and non-diminishing flows at the limb, Antiochos(1984) introduced the concept of a *chromospheric well*, which is formed due to the enhanced localized pressure due to impulsive heating. Under this scenario, the absence of CLV naturally arises due to projection effects. However, under impulsive heating, field-aligned hydrodynamical simulations show downflows with much lower amplitude than those observed at similar temperatures. Based on simulations, the speed of downflows in Si IV line should be less than $\sim$0.1 km s^{-1}, which is about two orders of magnitude lower than observed velocities. To account for this discrepancy between observed and simulated downflows in the Si IV line, Ghosh et al(2019) suggested that the downflows observed in the transition regions may be related to the downflow of type-II spicules, which get heated to 10^5 K. These may be surrounded by *chromospheric wall* formed by cold spicules heated to a temperature of about 10^4. They argued that the optical depth of surrounding cold spicules is close to but less than unity, hence, allowing some center to limb variation in Si IV line. Here **Abhishek Rajhans and Durgesh Tripathi** with collaborators, perform a comprehensive measurement of Doppler shifts in the transition region and its center-to-limb variation (CLV) in the strong field regions ($|\mathbf{B}| \geq 50$ G) of 50 active regions (ARs), using the Si IV 1394 Å line recorded by the Interface Region Imaging Spectrometer(IRIS) (see Figure 20). Our observations do not support the idea that redshifts in the lower transition region (T $<\sim$ 0.1 MK) are produced by field-aligned downflows as a result of impulsive heating and warrant an alternative interpretation, such as downflow of type-II spicules in the presence of a chromospheric wall created by cooler type-I spicules.

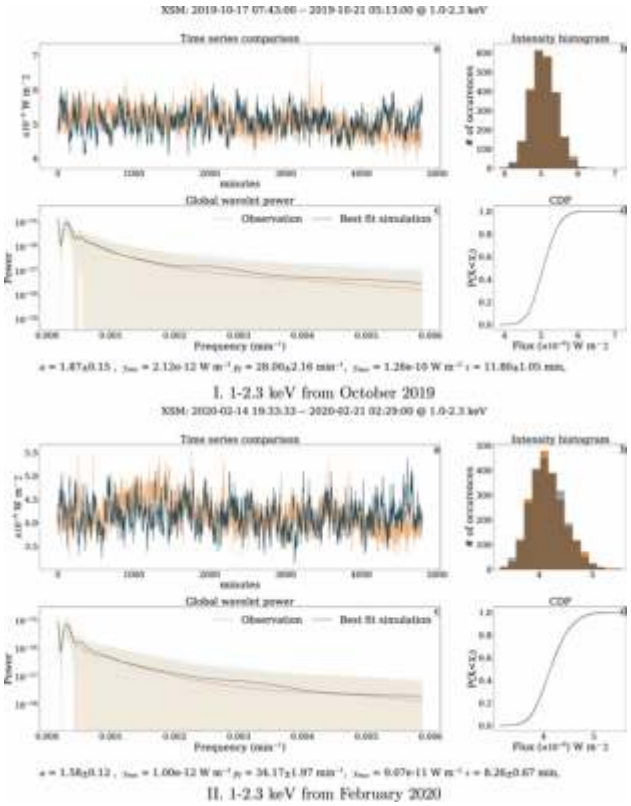


Figure 19: Comparison of the observed light curve from XSM (orange), and the PSM forward model of best-fit parameters inferred from our inversion code (black) in 1–2.3 keV energy band from 2019 (subfigure: I) and 2020 (subfigure: II). Each subfigure has four panels depicting the following. Panel (a): observed and simulated light curves. Panel (b): distribution of observed and simulated light-curve intensities. Panel (c): global Morlét power for observation and simulations, with the uncertainties presented in orange and blue bands. Panel (d): comparison of simulation and observation intensity CDF. The inset reports the inferred parameter set for the respective data.

QUANTUM TECHNOLOGIES

Precision & Quantum Measurement laboratory (PQM-lab: https://pqmlab.iucaa.in/)

Present team members -Sankalpa Banerjee (doctoral student), Rajesh Chell (doctoral student), Aman Gangwar (research fellow), Stanley Johnson (research associate), Sujaya Das Gupta (research associate), Sankar Majhi (scientific officer) and Subhadeep De (project investigator)

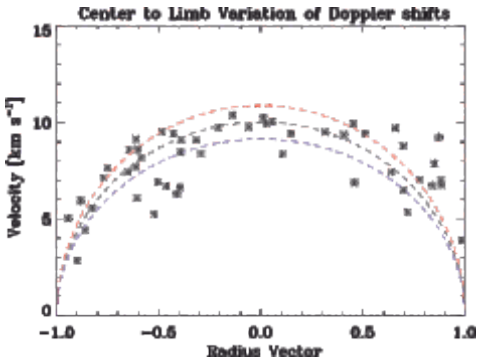


Figure 20: Measured Doppler shifts in the strong field regions of the active region as a function of radius vector shown with black asterisks. The dashed black curve shows the variation of Doppler velocity expected from the hypothetical vertical flow of $v_{vertical} = 10$ km s^{-1}. The over-plotted blue and red dashed lines show the CLV of hypothetical vertical flows with velocities $v_{vertical} - \delta v_{sys}$ (blue), and $v_{vertical} + \delta v_{sys}$ (red). The random errors range from 0.01 km s^{-1} to 0.2 km s^{-1}. Consequently, these errors are hardly visible.

Research

Figure 21: The Precision & Quantum Measurement laboratory (PQM-lab), at IUCAA.

The Precision & Quantum Measurement Laboratory (PQM-lab), as shown in the photograph (Fig.1), is developing a state-of-the-art facility dedicated to explore the fundamental aspects of science. The research interests of the lab involve developing quantum phenomena-based technologies for precision measurement and metrology, and accurate sensing. For that at present, the lab is actively involved in the development of the complex experimental set up which involves an optical atomic clock exploiting the highly forbidden octupole transition of Ytterbium-ion $^{171}Yb^{+}$ at 467 nm wavelength. The octupole transition in Yb-ion has an extremely low probability of occurrence, causing it to have less sensitivity to external perturbation and hence serves as an ideal candidate to build an atomic clock as well as this transition has the highest sensitivity for the measurement

of temporal constancy of the fine structure constant and possible violation of the Lorenz symmetry. The entire experimental setup includes a range of sophisticated technologies like ion trapping, generation of narrow linewidth ultra-stable laser, optical frequency synthesis, and phase-preserved dissemination of reference photons. The long-term plan of the PQM lab involves working on three major interconnecting areas. The first area is focused on establishing a lab-based reference optical clock. The second area involves developing ultra-stable optical links that will allow for networking among distant optical clocks. Finally, the third area is centered around the development of a chip ion trap, which has the potential to revolutionize the field of quantum information processing (QIP) and miniaturing of the technology. These three areas of focus are interconnected and will enable the lab to make significant contributions in the fields of quantum technology, quantum metrology & sensing, which are fully aligned with the National Quantum Mission.

Fabry Perot Cavity

An ultra-stable Fabry Perot (FP) cavity is an essential prerequisite for generating the narrow linewidth ultra-stable laser which is one of the major building blocks for an optical atomic clock. A 1550 nm commercial laser frequency stabilized to an indigenously developed ultra-stable FP cavity using Pound-Drever-Hall (PDH) technique will be utilized for this purpose. FP-cavity can transfer its length stability ($\Delta L/L$) to the laser frequency stability ($\Delta\nu/\nu$) following as, $\Delta L/L = \Delta\nu/\nu$. To reach an unprecedented level of stability $\Delta L/L$ of $\sim 10^{-16}$ we have to minimize instabilities caused by all the possible sources of noise. Initially, optical calculations are performed to optimize the length of the cavity so that minimum power is coupled to higher order modes (HOMs) also making sure there is no frequency overlap with any HOMs of the preceding fundamental modes (FMs). We optimized a length (L) of 293.4 mm and a hemispherical cavity with the radius of curvatures (ROC) of both the mirrors as 1 m and ∞, respectively. After considering combinations of spacer and mirror substrate based on its coefficient of thermal expansion (CTE) and its variation with temperature, Brownian noise, mechanical quality factor, aging, and ease of fabrication, fused silica (FS) for mirror and ultra-low expansion (ULE) glass as spacer substrate are concluded as a suitable option. Following the selection of material, length, and type of FP-cavity, Finite Element Analysis (FEA) was performed for decreasing thermo-mechanical noises coupling to the cavity. The

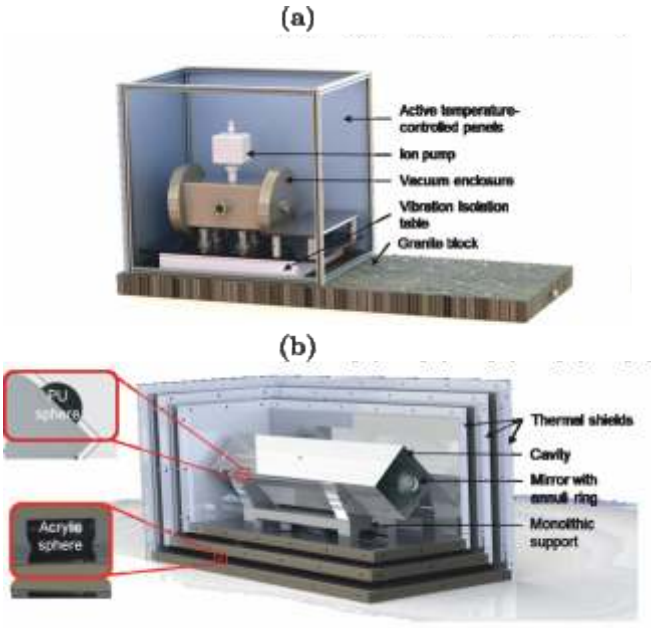


Figure 22: (a) Vacuum chamber with active vibration isolation table, ion pump, and active temperature-controlled panels. (b) Cavity with three layers of thermal shielding.

cavity will be affected by its self-weight and we have put the cavity in the optimal points of support, to minimize its length deformation, known as the Airy points. This is also indicative of the vertical acceleration sensitivity of the cavity resulting in lower vibration sensitivity. A mirror offset from the central axis of the cavity is considered to further reduce the effect of length change due to the Poisson's effect. We obtained a fractional length deformation for self-weight as $\Delta L/L = 1.1 \times 10^{-12}$. One of the important instabilities affecting the cavity is $\Delta L/L$ due to temperature fluctuation, the cavity is kept within three layers of thermal shielding separated by three-point contact using acrylic spheres and the entire assembly is put inside a vacuum chamber with air pressure less than 1×10^{-7} mbar to eliminate convection and limit conduction as shown in Fig. 2(a-b). The only dominant heat transfer is thermal radiation giving a $1/e$ time period of 6.53 days. Further, the entire assembly will be inside an active temperature-controlled enclosure to keep the cavity at its effective zero-crossing temperature (T_o), keeping the cavity at $T_o \pm 5$ mK will result in an Allan deviation (ADEV) frequency instability of 2.42×10^{-16} at $1s$ integration time.
Different methods are explored for estimating

vibration-induced instabilities coupling to the cavity. One of the commonly reported methods is to measure acceleration sensitivity along the gravity or along three mutually perpendicular directions, which are named method-1 and 2 respectively. The random vibration analysis, that is method-3, uses modal or natural frequency analysis within 0-2000 Hz bandwidth. This method is computationally very expensive and input/output are in the form of power spectral density. This makes instability due to length deformation and misalignment of the cavity indistinguishable. We have proposed another approach called forced vibration (method-4), which uses modal analysis as well as acceleration sensitivity in all three axes. The output of this method is the time-dependent displacement of the centre of the mirrors, which allowed us to consider instability due to changes in length and misalignment of the cavity separately. To establish confidence in the proposed methods (1-4) we used experimental results reported by M. D. Alvarez [Ref.: Optical cavities for optical atomic clocks, atom interferometry, and gravitational-wave detection, Springer (2019)], and compared those with our simulated results in Tab. 1. It is evident that method-4 best replicates the experimental results. Implementing method-4 on 293.4 mm long FP-cavity, the ADEV of frequency instability due to vibration is 5.8×10^{-18} at 1 s integration time. Considering all the above-mentioned instabilities, the combined fractional frequency instability ADEV at 1 s and 1 week integration time are $2.59 \times 10{-}16$ and 8.5×10^{-17}, respectively. Our theoretical result with dielectric and crystalline mirrors (green and magenta respectively) is compared with the reported stabilities of different ultra-stable FP cavities throughout the world, operating near room temperature (red) and cryogenic (blue), around the world and depicted in figure 23.

Fiber phase stabilization for ultra-stable optical frequency transmission

Ultra-stable frequency transmission between distant laboratories is required for intercomparison of the optical clocks, time and frequency metrology, synchronizing detectors in particle accelerators, synchronization of deep-space network, and synchronization among the astronomical antenna arrays. As a consequence, an ultra-stable frequency transmission with a fractional frequency instability of 10^{-18} (or below) in one day is required to compare the frequency of present (and future) optical clocks over large distances. Long-distance frequency comparisons of ultra-stable clocks enable us to evaluate not only the performance of these clocks, the geoid fluctuations and verify the consistency of fundamental constants. The mature satellite-based links for frequency comparison show a fractional instability of about 10^{-15} for one-day integration, which is not suitable for comparing highly accurate clocks of fractional accuracy $\sim 10^{-18}$. Therefore, ground links with better stability are required to compare the frequency of the optical clocks. Fibre networks are the best candidates for the ground links to transfer an ultra-stable frequency, due to their good intrinsic stability, low loss, reliability, and wide accessibility. The goal of an optical link is to reproduce a local frequency reference at the remote end of the fiber link. Several noises accumulated along the optical fiber degrade the transferred frequency signal by perturbing its phase. For instance, thermal and mechanical fluctuations change the optical path through the fiber, thus inducing fluctuations of the propagation delay. The delay fluctuations correspond to phase/frequency variations of the transferred signal. The scheme is shown in figure 24. below where the link is the optical fiber. It is actually a general scheme of Doppler noise cancellation for signal transmission. The local system compares the round-trip signal to the local signal, therefore, measures the sum of the forward and backward phase fluctuations of the propagating signals. The phase fluctuation of the fibre is mainly induced by the length and refractive index variations, which equally impact the forward and backward propagation phases approximately. Therefore, the phase fluctuation of forward transmission is half of the round-trip phase fluctuation, and it can be measured and compensated. At the PQM lab, we have developed fiber phase stabilization system for transmitting optical atomic clock signals. Our testing involved utilizing a commercial 1550 nm laser with a sub-hertz linewidth as the frequency source, along with both a 72 km long fiber spool and a 4 km underground fiber. The fiber phase stabilization system performed exceptionally well during testing, exhibiting a fractional instability in the range of 10^{-19} over an integration time of 10^4 seconds. This level of stability is very close to the fundamental limitation caused by the link delay, indicating the high effectiveness of our fiber phase stabilization technology.

Table 1: Instability of the cavity due to vibrations at $1g$ calculated using different methods.

Method	Method-1	Method-2	Method-3	Method-4	Experimental
$\Delta\nu/\nu \times 10^{-11}/g$	2.5	20	4.55	58.4	59

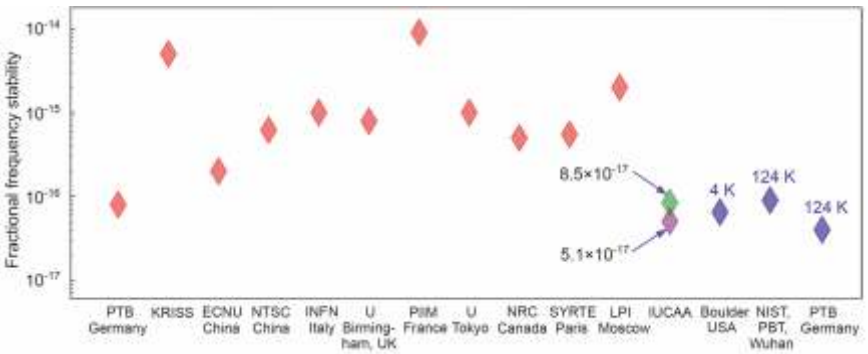


Figure 23: Reported stabilities of FP cavities around the world at room temperature (red), cryogenic (blue) and present simulation with dielectric and crystalline mirrors (green and magenta respectively).

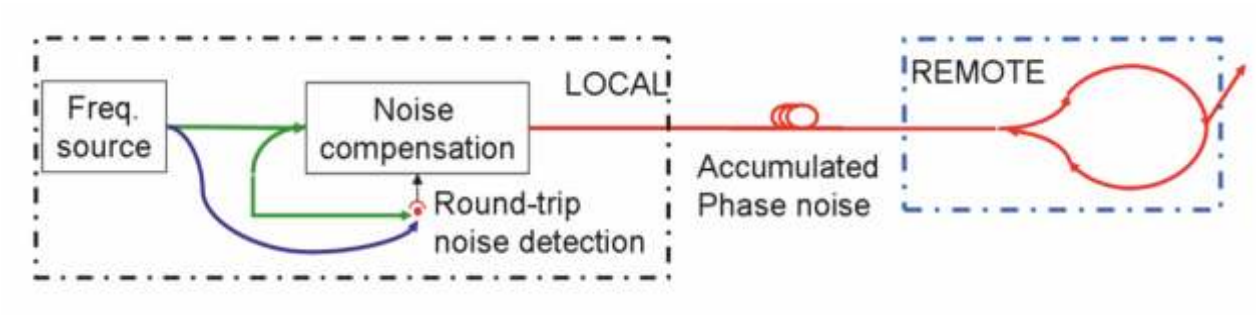


Figure 24: General scheme for the noise compensation of frequency transfer.

PEDAGOGICAL

(a) IUCAA – NCRA Graduate School

Debarati Chatterjee

Quantum and Statistical Mechanics II (14 lectures) (October – December 2022)

Neeraj Gupta

Interstellar Medium (14 lectures)

Ranjeev Misra

Electrodynamics and Radiative Processes II (14 lectures) (October – December 2022)

Sanjit Mitra

Topical course on Gravitational Waves (14 lectures) (May – June 2022)

Surhud More

Extragalactic Astronomy II (14 lectures) (January - March, 2023)

Sowgat Muzahid

Astronomical Technique –I (14 lectures) (March-May, 2022) Astronomical Technique – I, Semester 2 (14 lectures) (January - March 2023)

Aseem Paranjape

Methods of Mathematical Physics II (14 lectures) (October – December 2022)

Research Methodology and Statistical Techniques I (7 lectures) (January - March 2023)

Kanak Saha

Galaxies: structure, dynamics, and evolution 2023 (21 lectures) (January - March 2023)

Nishant Singh

Methods of Mathematical Physics I (14 lectures) (August – October 2022)

Raghunathan Srianand

Research Methodology and Statistical Techniques I (7 lectures) (January - March 2023)

Extra-galactic Astronomy II (14 lectures) (2022 – 2023)

Kandaswamy Subramanian

Quantum and Statistical Mechanics I (14 lectures) (August – October 2022)

(b) SPPU-IUCAA Joint M.Sc Physics (Astrophysics) Programme

Gulab Chand Dewangan

High-Energy Astrophysics, Semester IV

Neeraj Gupta

Astronomical Techniques

Ranjan Gupta

Msc, A \& A Semester III \& IV laboratory course for the Pune University Physics and Space Sciences departments. This involves set of 10 nos. of theory lectures related to observational astronomy and a set of 10 laboratory and night experiments.

Shasvath Kapadia

General Relativity and Cosmology, Semester IV (40 lectures) (Springer 2023)

Sanjit Mitra

Relativistic Electrodynamics and Radiation Processes (July – November 2022)

Dipanjan Mukherjee

Astrophysical Dynamics, Semester IV

Vaidehi S. Paliya

Introduction to Astronomy and Astrophysics (PHY-IC381 and PHY-S357) (45 lecture)

(c) Savitribai Phule Pune University B.Sc IDSS Lectures

Dhruba J. Saikia

Introductory Astronomy and Astrophysics (10 lectures) (March 2023)

(d) SUPERVISION OF Ph.D. THESIS (Degrees Awarded)

Sukanta Bose

Title: *Strong gravity physics of dynamical horizons in black hole mergers and its imprint in their gravitational radiation*
Student: Vaishak Prasad (IUCAA)

Gulab Dewangan

Title: *Accretion Disk/Corona Emission from Active Galactic Nuclei*
Student: Prakash Tripathi [IUCAA]

A.N. Ramaprakash

Title: *A new memory principle-based speckle correlation imaging technique through atmospheric turbulence*
Student: Sorabh Chhabra [IUCAA]

Title: *Design and Development of Wide-Field Linear Optical Polarimeters (WALOP) for PASIPHAE Sky Survey*
Student: Siddharth Maharana [IUCAA]

Tarun Souradeep

Title: *Precision Cosmology from Cosmic Microwave Background Weak Lensing*
Student: Rajorshi Chandra [IUCAA]

Durgesh Tripathi

Title: *Heating and Dynamics of the Solar Atmosphere*
Student: Vishal Upendran [IUCAA]

Title: *Energetics of the solar atmosphere*
Student: Abhishek Rajhans [IUCAA]

(e) SUPERVISION OF Ph.D. THESIS (Ongoing)

Debarati Chatterjee

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

Title: *Study of the effect of Neutron Star composition on fluid oscillation modes and Gravitational Wave emission.*
Student: Bikram Keshari Pradhan

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

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

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

Gulab Chand Dewangan

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

Title: *Accretion disk-corona interplay in Active Galactic Nuclei*
Student: Kavita Kumari [IUCAA]

Title: Active Galactic Nuclei and Bright UV Sources in the AstroSat/UVIT Field
Student: Piyali Ganguli [IUCAA]

Neeraj Gupta

Title: *An unbiased view of cold atomic gas associated with radio-loud AGNs [IUCAA]*
Student: Partha Deka

Shasvath J. Kapadia

Title: *Identifying accelerated compact binary coalescence events with current and future gravitational-wave detectors*
Student: Avinash Tiwari

Title: *Observing lensed and unlensed gravitational-waves in current and future-generation gravitational-wave detectors*
Student: Sourabh Magare [Co-supervised with Anupreeta More]

Sanjit Mitra

Title: *Efficient Searches for Compact Binary Coalescences and Science in the LIGO-India Era.*
Student: Kanchan Soni [IUCAA]

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

Title: *Algorithms for Gravitational Wave Data Analysis and Detector Controls Based on Modern Techniques.*
Student: Shreejit Jadhav [IUCAA]

Anupreeta More

Title: *Using Gravitational waves from compact binary coalescences to probe gravitational lensing (strong and micro) and the magnetic Penrose processes*
Student: Anuj Mishra [IUCAA] [Co-supervised with Sukanta Bose]

Surhud More

Title: *Gravitational Lensing in Galaxy Clusters*
Student: Amit Kumar [IUCAA]

Title: *Probing Cosmology with Large Scale Structure Correlations*
Student: Divya Rana [IUCAA]

Surhud More Co-supervised with Anupreeta More

Title: *The Galaxy Dark Matter Connection*
Student: Navin Chaurasiya [IUCAA]

Title: *Gravitational Lensing probes of Dark Matter.*
Student: Priyanka Gawade Amit Kumar [IUCAA]

Dipanjan Mukherjee

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

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

Title: *Simulations of various aspects of extra-galactic, relativistic jets*
Student: Prathamesh Ratnaparkhi

Title: *Magnetic fields of Accreting Neutron Stars*
Student: Saurabh Yeole.

Sowgat Muzahid

Title: *Gaseous atmospheres of high redshift Ly*
Student: Eshita Banerjee (IUCAA)

Title: *Probing the Circumgalactic Medium of Low Redshift Galaxies*
Student: Sayak Dutta (IUCAA)

Vaidehi S. Paliya

Title: *High Energy Transients: A multi-wavelength prospective*
Student: Suvas Chandra Chaudhary (IUCAA)

Aseem Paranjape

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

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

Title: Cosmic velocity flows: from theory to observations
Student: Saee Dhawalikar

Kanak Saha

Title: *Probing the ionizing radia/on of high-redshi3 galaxies using AstroSat*
Student: Soumil Maulick (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)

Title: Thesis title yet to be finalized
Student: Jyoti Prakash (IUCAA)

Raghunathan Srianand

Title: *Probing the Ultra-Fast Outflows in BAL Quasars using Multi-Epoch Spectroscopy.*
Student: P. Aromal (IUCAA)

Title: *Probing the Nature, Environment and Evolution of Ultra Strong Mg II absorption System.*
Student: Labanya Guha (IUCAA)

Title: *Exploring the Metals in the Intergalactic Medium.*
Student: Sukanya Mallik (IUCAA)

Nishant Singh

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

Durgesh Tripathi

Title: *Dynamics of the Lower Solar Atmosphere*
Student: Soumya Roy

Title: *A Study of Transients in the Solar Atmosphere*
Student: *Biswanath Malaker*

(f) SUPERVISION OF Ph.D. THESES

(Degrees ongoing – Other than IUCAA)

Neeraj Gupta

Student: Eric Maina - SARAO, South Africa (co-supervisor, since 2019)

Student: Jonah Wagenveld - MPIfR, Germany (mentor, since 2019)

Shivaraj Kandhasamy

Title: Searches for stochastic gravitational-wave background in advanced LIGO data
Student: Junaid Yousuf (University of Kashmir, Srinagar)

Nishant Singh

Title: *On effects of small-scale turbulence on the acceleration of cosmic rays*
Student: Sayan Kundu (IIT-Indore)

Title: *On magnetic fields of disc galaxies*
Student: Subah Sharma (Thapar Institute of Engineering and Tech, Patiala)

Durgesh Tripathi

Title: *Study of the Solar Atmosphere: Space Instrumentation and Observations*
Student: Janmejoy Sarkar

(f) SUPERVISION OF MS THESES

T. P. Singh

Title: *Spontaneous Collapse Models from a coarse-grained Deterministic and Non-unitary Dynamics*
Student: Kartik Kakade (IISER Pune)

Title: *The CKM matrix from an algebra*
Student: Aditya Ankur Patel (IISER Mohali)

(g) SUPERVISION OF PROJECTS

Debarati Chatterjee

Kuldeep Singh (SPPU-IUCAA M.Sc. with Astrophysics) *Constraining effective nucleon mass using multi messenger observations.*

Nilaksha Barman (IUCAA Graduate School) *A code to calculate Nuclear Statistical Equilibrium condition for the CompOSE database.*

Pranjal Tambe (IUCAA Graduate School) *Study of suprathermal bulk viscosity in Neutron Stars due to magnetic field effects.*

Apratim Ganguly

Anik Mandal (SPPU-IUCAA) *Biases in tests of general relativity due to eccentric signals*
[in collaboration with Prof. Sanjit Mitra]

Anirudh Srivastha Nemmani (IISER Tirupati) *How good is isolated microlensing approximation?* [Vacation Students' Program 2022]

Surendra Bhattarai (IISER Kolkata) *Can eccentric signals mimic microlensing?*

Nishkal Rao (IISER Pune) *Can overlapping signals mimic any other physical effects?*
[in collaboration with Dr. Anupreeta More]

Neeraj Gupta

Sachin Joshi SPPU-IUCAA project (3rd + 4th semester)

Shivaraj Kandhasamy

Pritam Sarkar (IIT, Kharagpur) *Modeling and simulation of suspended mirrors and Fabry-Perot cavities using LIGO's control and data system software.*

Vishakha Potdar (SPPU) *Virtual LIGO Gravitational Wave Detector*

Shasvath J. Kapadia

Sudhir Gholap (IUCAA Graduate School) *A template-based method for the identification of strongly lensed gravitational-wave events*

Gopal Prabhu (IUCAA Graduate School) *Constraining the abundance of exotic compact objects in our galaxy with gravitational-waves*

Poorva Pawar (SPPU BSc/MSc) *Gravitational-Wave Data Analysis*

Kajol Shelke (SPPU BSc/MSc) *Identification in detector data of overlapping gravitational-wave signals from compact binary coalescences*

Sanjit Mitra

Sakshi Kumar (IIT-Kharagpur) B. Tech. Project

Ashish Mhaske (BITS Pilani) M. Tech. Project

Anupreeta More

Prajakta Mane (IISER Mohali) *Identifying the Lensed Supernovae from LSST Data,* (Co-supervised with Surhud More)

Soorya Narayan (IISER Pune) *Machine learning algorithm to identify gravitational lensing and gravitational wave sources*

Arjun Murlidharan (IISER Pune), *Quadruply Lensed Quasars* (Co-supervised with Somak Raychaudhaury)

Surhud More

Parmeshwar Dewangan (SPPU/IUCAA) *An observational search for infalling galaxy groups into clusters*

Esha Garg (IIT Roorkee) *The assembly bias of halos defined according to the splashback radius*

Sowgat Muzahid

Sourav Das (IUCAA-SPPU M.Sc. Course) *Probing the azimuthal distribution of circumgalactic medium in low redshift galaxies.*

Vaidehi S. Paliya

Sanjay Maurya (IUCAA-SPPU M.Sc. Astrophysics), *Compton dominance-based classification of Fermi blazar candidates of uncertain type*

Preetam Biswas (SPPU M.Sc. Physics), *Radio morphology of gamma-ray sources*

Suresh Parekh (SPPU M.Sc. Physics), *Extended X-ray jets associated with radio-loud quasars*

Kaustav Bhattacharya (SPPU M.Sc. Physics), *Identification of Multiwavelength counterpart of unclassified Fermi detected gamma-ray objects*

Aseem Paranjape

Mr. Kaustubh Gupta, VSP project Sept-Oct 2022

Ms. Pooja Thakur, VSP project Sept-Oct 2022

Mr. Biplab Sarkar, SPPU-IUCAA project (3rd + 4th semester)

Kanak Saha

Arghya Chakraborty (IISER Tirupati, M.Sc. Final year thesis (submitted)), *Multiwavelength Analysis of Interacting Galaxy Pair Arp 297*, 2022 - 2023

Raghunathan Srianand

Varun Nikham, IIST, Thiruvananthapuram *Spectral energy distribution from the accretion disks*

Dhruba J. Saikia

Kshitij Chavan (Savitribai Phule Pune University) *Double-double radio galaxies* (Co-Supervised by Pratik Dabhade).

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

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

Nishant Singh

Yash Koushal (IUCAA-SPPU M. Sc. Physics with Astrophysics), *Solar f mode based precursor to predict the formation of Active Region* (2022 – 2023)

Dhruv Pandya (IUCAA), *MHD waves in the inhomogeneous medium: implications for heating in solar atmosphere*

(h) SEMINARS, COLLOQUIA, AND LECTURES

Prakash Arumugasamy

Stellarium, [two lectures] 17 and 24 May 2022 during the Online Refresher Course on Astronomy and Astrophysics, 16 May - 17 June 2022.

Six lectures were delivered during the TLC online course *'Fundamentals of Astronomy using Stellarium'* from 8 to 26 August 2022.

Antenna & Radiometer characteristics, IUCAA–NCRA Radio Astronomy Winter School 2022, IUCAA, Pune, 13 December 2022.

Teaching Learning Session, Introductory Course on Astronomy and Astrophysics for College Teachers, Online, 27 March 2023.

Debarati Chatterjee

Hints from Multi-disciplinary Physics to probe the Neutron Star interior, invited talk for the series "Istanbul University Observatory Astrophysics Talks", May 2, 2022.

Hints from Multi-disciplinary Physics to probe dense matter in Neutron Stars, invited seminar at Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Bucharest, Romania, Oct 27, 2022.

Gravitational Waves as a tool to probe dense matter in Neutron Stars, invited talk at LuTh, Observatoire de Paris, Meudon, France, Nov 17, 2022

Constraining Neutron Star composition with hints from multi-disciplinary physics, invited seminar for AstroCoffee, ITP Goethe University, Frankfurt, Germany, Nov 29, 2022.

Hints from Multi-disciplinary Physics to probe dense matter in Neutron Stars, invited colloquium at the National Centre for Radio Astrophysics (NCRA), Pune, June 10, 2022.

Gravitational Waves from Neutron Stars to probe Extreme Physics, invited talk at ECU2023 (The 2nd Electronic Conference on Universe) Session 2: Women Scientists in Astronomy, Astrophysics and Cosmology, live on YouTube, Feb 27, 2023

Probing ultradense matter in Neutron Stars with Gravitational Waves invited plenary lecture at the 41st Meeting of the Astronomical Society of India, Indore, March 3, 2023

Subhadeep De

Development of an Optical Atomic Clock for Fundamental Science Experiments, Asian International Seminar on Atomic and Molecular Physics 2023 (online).

The Trapped ions, Symposium in Quantum Computing Frontiers: Basics & Building Blocks, CDAC Pune, 30 – 31 January 2023.

Measuring Constancy of the Fundamental Constants Using Atomic Clocks, The constancy of the fundamental "constants?", IUCAA, Pune, 1-2 December 2022.

Indigenization of Technologies Required to Build the Quantum Clock, Joint Indo-Russia Meeting on QT, I-HUB QTF at IISER Pune, 21-22 August 2022.

Progress towards development of the optical atomic clock at IUCAA, Physics with trapped atoms, molecules, ions, ICTS, 09-13 May 2022.

Progress on IUCAA's optical atomic clock, QuEST National Symposium, 13 April 2022.

Gulab Chand Dewangan

Accretion disk/corona emission from Active Galactic Nuclei, 5th National conference on REcent Trends in the study of Compact Objects (RETCO-V): Theory and Observation, 3 – 5 April 2023, Kodaikanal Solar Observatory, India. (Online)

X-ray Winds and Outflows in Active Galactic Nuclei, GALFLOWS, A National Workshop on Galactic inflows and outflows on all Scales, IUCAA, 2 – 5 February 2023.

AstroSat -- India's first multi-wavelength space observatory, International Workshop – Science & Technology, Pt. RSU Raipur, 15 – 18 October 2022.

Broadband Spectroscopy of BHB/AGN: CZTI perspective, CZTI workshop, IUCAA, 15 – 16 September 2022.

Multi-wavelength Studies with AstroSat, Seven years of AstroSat conference, ISRO Head quarters, Bangalore 28-29 September 2022

Cross-calibration & Future Plans, AstroSat Calibration workshop, IUCAA, Pune, 24 August 2022

X-ray Spectral Response, 1st National Workshop on GIANT4 and its application to High Enery Physics \& Astropgysics, IUCAA Pune, 5 – 9 December 2022.

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

Apratim Ganguly

Gravitational-Wave Data Analysis - a quick primer, IISER-Thiruvananthapuram, Anvesha'22, 7 November 2022

Gravitational-Wave Data Analysis - a quick primer, IISER-Tirupati, Aethereum'22, 12 November 2022

Gravitational Lensing of Gravitational Waves, IIT-Tirupati, Aethereum'22, 13 November 2022

Microlensed gravitational wave signals: Biases in tests of GR, IISER-Kolkata, IAGRG32, 19 December 2022

Neeraj Gupta

The MeerKAT Absorption Line Survey, Colloquium at NRAO, USA, 6 May 2022

The MeerKAT Absorption Line Survey: Evolution of cold gas in galaxies, Plenary talk, The Annual Meeting of ASI, 4 March 2023

Ranjan Gupta

Careers in Astronomy, Online talk at Nehru Planetarium, New Delhi, 14 April 2022.

Laboratory Study of Regolith Analogues: Relevance to recent Asteroid sample return missions, Talk delivered at MPIA, Heidelberg, Germany on 30 June 2022.

India Report on Astronomy Updates, Online talk given during October 18-20, 2022, at BRICS Astronomy Working Group Meeting held at NOAC, Beijing, China.

Recent Asteroid Sample Return Missions – related Laboratory Experiments, two talks given at Central University, Kishangarh, Rajasthan, during 6-7 January 2023 at the IWCMDA2023 workshop.

Shivaraj Kandhasamy

Update on the stochastic search group activities, LIGO-Virgo-KAGRA collaboration meeting, Cardiff University, UK, 15 September 2022. (Online)

Jetted Narrow-Line Seyfert 1 Galaxies in Fermi Era, invited review talk in '4th National Conference on High Energy Emission from Active Galactic Nuclei' conference, Aug 12-14, 2022, Farook College, Calicut, India

Introduction to the Gamma-ray Universe, IUCAA-sponsored national conference "National Seminar on Advances in Astrophysics & Space Science Research 2023" organized by CHRIST (deemed to be university), Bangalore from February 13-15, 2023.

Jameer Manur

(Lectures delivered as a part of TLC activities)

Need for Telescopes, S.P. College, Pune, 16 February 2023

Listening to the Universe by tuning into the Radio, Modern College, Pune, 25 March 2023

Observational Astronomy, VIT College, Pune, 29 March 2023

Introduction to Astronomy, Gunjal College, Sangamner, 11 April 2023

Sanjit Mitra

Mapping the Anisotropic Stochastic Gravitational-Wave Background With Ground-based Detectors, invited talk, U C Louvain, Belgium, 9 September 2022

LIGO-India Status update, LVK meeting, Cardiff University, UK, September 15, 2022

Cosmology potential with a Decihertz gravitational wave observatory, invited talk, SINP, Kolkata, 25 January 2023.

Neutron star science potential with a Decihertz gravitational wave observatory, invited talk, IMSc, Chennai, 3 February 2023

Gravitational Wave Astronomy: Present status & future prospects, National Science Day Lecture, CSIR-NGRI, Hyderabad, 1 March 2023

Mega-science Projects in Astronomy & Astrophysics, invited special seminar, BITS-Mesra, 18 March 2023

Surhud More

Strong gravitational lensing", ISSAA 2022, IUCAA, 9 June 2022

Detection of Gravitational wave sources and gravitational lensing effects, UIB, Spain, 1 July 2022 (Online)

Gravitational waves and gravitational lensing, ISSI Workshop, Switzerland, 20 July 2022

Detection of Gravitational wave sources and gravitational lensing effects, invited talk, Exploring the Energetic Universe 2022, ECL, Kazakhstan, 1 September 2022 (Online)

Detection of Gravitational wave sources and gravitational lensing effects, Nagoya, Japan, 21 October 2022

Detection of Gravitational wave sources and gravitational lensing effects, Kindai, Japan, 25 October 2022

Detection of Gravitational wave sources and gravitational lensing effects, Kavli IPMU, Japan, 27 October 2022

Gravitational lensing and gravitational waves: Tensions in cosmology, plenary talk, IAGRG 2022, IISER Kolkata, 19 December 2022

Gravitational lensing and gravitational waves: Tensions in cosmology, invited lecture, LTPDU 2023, ICTS, Bangalore, 20 March 2023

Weak gravitational lensing, inaugural school of the Indian Association for General Relativity and Gravitation, May 23-28, 2022

Cosmology, Olympiad camp, June 15 2022

Gravitational lensing, IUCAA Summer School cum Refresher Course, June 8, 9, 10, 2022

The search for Planet Nine using the Subaru Telescope, IAU General Assembly, Busan, South Korea, Aug 3, 2022

IUCAA Scipop: Astronomy outreach in India during the COVID era, IAU General Assembly, Busan, South Korea, Aug 5, 2022

Difference imaging with the Rubin science pipelines, The Dark Energy Survey Collaboration meeting, Aug 9, 2022

Cosmology and Astrophysics from the Subaru Hyper Suprime-Cam survey, Colloquium at Presidency University, Oct 12, 2022

The Subaru search for Planet Nine, Nagoya University, Japan, 20 Oct, 2022

The Subaru search for Planet Nine, NAOJ, Japan, 27 Oct, 2022

The Subaru search for Planet Nine, APEC Kavli IPMU, Japan, 28 Oct, 2022

The search for Planet Nine, Marathi Khagol sammelan, Fergusson College Pune, Jan 27, 2023

The Indian participation in Rubin LSST, Rubin LSST, Astronomical Society of India meeting, Mar 1, 2023

Subaru Search for Planet Nine, Astronomical Society of India meeting, Mar 2, 2023

GW cosmology (sirens and mass spectral features), invited plenary talk at Moriond conference, La Thuille, Italy, Mar 20, 2023,

Astrophysics from the Subaru Hyper Suprime-Cam Survey, Universitaet Zurich, Switzerland, Mar 27, 2023

Dipanjan Mukherjee

Simulating young magnetised jets from supermassive black holes, invited plenary talk, ASI 2022 meeting, IIT Roorkee, 27 March 2022

Virtual seminar at University of Cardiff, on 19th October 2022

Physics of relativistic jets on all scales, invited talk, IAUGA Focus meeting, Busan Korea 2nd and 9th August 2022. (Online)

High Energy Emission from Active Galactic Nuclei, invited talk, 4th National Conference on High Energy Emission from Active Galactic Nuclei, Farook College, Kozhikode, Kerala, 12 – 14 August 2022.

Invited talk, the APPC15, a virtual meeting of the 15th Asia Pacific Physics Conference, 21 – 26 August, 2022. (Online)

Unveiling the role of relativistic jets in galaxy evolution through MHD simulations, invited talk, the AAPPS-DPP 2022, virtual meeting of 6th Asia-Pacific Conference on Plasma Physics, 9 – 14 October, 2022. (Online)

Understanding how jets from Supermassive Black Holes affect galaxy evolution, invited talk, the National Seminar on Advances in Astrophysics & Space Science Research 2023, Christ University, Bangalore on 14th February, 2023

Sowgat Muzahid

The MUSEQuBES Surveys On the CGM, What matter(s) around galaxies 2022: connecting the dots between the circumgalactic medium and the larger-scale environment, Champoluc, 12 September 2022

Observational Signatures of Diffuse Gas Flows in Galaxies, GALFLOWS-2023, IUCAA, Pune, 4 February 2023

Galaxies, Clusters, and IGM, ASI decadal vision document, ICTS, Bangalore, 31 October 2022

J. V. Narlikar

Cambridge: My Alma Mater, IUCAA, Pune, June 28, 2022.

Vaidehi S. Paliya

Jetted Narrow-Line Seyfert 1 Galaxies in Fermi Era, invited review talk in '4th National Conference on High Energy Emission from Active Galactic Nuclei' conference, Aug 12-14, 2022, Farook College, Calicut, India

Introduction to the Gamma-ray Universe, IUCAA-sponsored national conference "National Seminar on Advances in Astrophysics & Space Science Research 2023" organized by CHRIST (deemed to be university), Bangalore from February 13-15, 2023.

Aseem Paranjape

The radial acceleration relation and external field effect in a LCDM universe, invited seminar at IFPU focus week on `Recent developments in theoretical Large-Scale Structure, IFPU, Trieste, 25 July 2022

Dark matter in Astrophysics, invited talk at a conference on `Particle Physics: Phenomena, Puzzles and Promises', ICTS Bangalore, Nov 2022

Shouvik Roy Choudhury

Massive Neutrino Interactions and Inflation, Dark Side of the Universe DSU 2022, UNSW Sydney, Australia, 5-9 Dec 2022.

Neutrinos in Cosmology, Academia Sinica Intitute of Astronomy and Astrophysics (ASIAA), Taipei, Taiwan, 2 Feb 2023.

Neutrino Self-Interactions. Hubble Tension, and Inflation, CERN Neutrino Platform Pheno Week 2023, Geneva, Switzerland, 13-17 Mar 2023 (attended online).

Massive Neutrino Self-Interactions and Inflation, Less Travelled Path to the Dark Universe, ICTS-TIFR, Bengaluru, India, 13-24 Mar 2023.

Neutrino Self-Interactions. Hubble Tension, and Inflation, Majorana-Raychaudhuri Seminar, a joint venture of INFN & University Salerno, Italy & PAMU, Indian Statistical Institute, Kolkata, India, 14 April 2023 (talk given online).

Neutrino Self-Interactions. Hubble Tension, and Inflation, Largest Cosmological Surveys and Big Data Science, ICTS-TIFR, Bengaluru, India, 9-12 May 2023.

Kanak Saha

Searching for galaxies that reionized the universe using AstroSat, invited talk, Deptartment of Physics, BHU, jointly organised by NASI, Varanasi, 28 December 2022

Probing galaxy formation using AstroSat, invited talk, National Student's Space Challenge, IIT Kharagpur, 6 November 2022

Faint galaxies from the AstroSat UV Deep Field, invited talk, LSST meeting at Europe, Rome, 25 October 2022

A re-ionizing galaxy from the Cosmic Dawn, invited talk, MUSE Busy week, Leiden, 19 October 2022

Spiral structure revisited, invited talk, Academy of Athens**,** Greece**,** One-day workshop, 14 October 2022

AstroSat Detection of Lyman Continuum emission from high-z galaxies, invited talk, 7 years of AstroSat, ISRO HQ, Bangalore, 28 September 2022.

An extraordinary escape of photons from a distant galaxy, invited talk, 15th Asia Pacific Physics Conference (APPC15), 25 August 2022 (Online)

Growth and survival of Bars in disk galaxies, invited talk, RCAAM, Academy of Athens**,** Greece, 5 July 2022

A re-ionizing galaxy from the Cosmic Dawn, invited talk at MUSE Busy week, 2 June 2022

Dhruba J. Saikia

Black holes in our Universe, (online) IEEE-AP-MTTS SBC, IIT Kharagpur, April 04, 2022.

Supermassive black holes and relativistic jets (2 lectures), IUCAA Summer School and Refresher Course on Astronomy and Astrophysics, Pune, 8 and 9 June 2022.

The Milky Way, IUCAA Summer School and Refresher Course on Astronomy and Astrophysics, Pune, 14 June 2022.

Galaxies and giant radio sources, Workshop on recent progress in astrophysics, Amity University, Noida, 17 November 2022. (Online)

Our multi-coloured Universe, MSFDA and ACE IUCAA workshop on Astronomy, Science and Society, TISS Tuljapur, 3 December 2022.

Breakthrough contributions by women in astronomy, MSFDA and ACE IUCAA workshop on Astronomy, Science and Society, TISS Tuljapur, 3 December 2022.

Radio galaxies and quasars, Radio Astronomy Winter School, IUCAA and NCRA Pune, 17 December 2022.

Building inclusive societies: perspectives from astronomy, MSFDA and ACE IUCAA workshop on Astronomy, Science and Society, Walchand College of Arts and Science, Solapur, 11 January 2023.

Building inclusive societies: lessons from astronomy, Tezpur University Foundation Day Lecture, Tezpur, 21 January 2023.

On the importance of building inclusive societies: perspectives of an astronomer, Assam Don Bosco University, Guwahati, 23 January 2023.

Exploring the Universe in the era of multi-messenger astronomy: a theme for quality improvement in liberal education, University of Science and Technology Meghalaya, Ri Bhoi District, 24 January 2023.

Inclusiveness, equity and equality: an astronomer's perspective, Cotton University, Guwahati, 25 January 2023.

Inclusiveness, diversity and equity in higher education: perspectives of an astronomer, Assam down town University, Guwahati, 27 January 2023.

Reflections on multi-disciplinarity, Workshop for Principals of Government Colleges of Maharashtra, Maharashtra State Faculty Development Academy, Pune, 3 March 2023.

Multi-messenger astronomy (online), Introductory Course on Astronomy and Astrophysics, ICARD Central University of Himachal Pradesh and ACE IUCAA, 22 March 2023.

Shilpa Sarkar

Imprints of spin on the solution and emission spectrum of accretion flows around black holes, invited talk, Fifth Virtual Workshop on Numerical Modeling in MHD and Plasma Physics : Methods, Tools, and Outcomes, Moscow, Russia, 12 – 14 October 2022. (Online)

Two-temperature accretion flows around compact objects, 32nd meeting of Indian Association for General Relativity and Gravitation (IAGRG32), IISER, Kolkata, 19 – 21 December 2022

Two-temperature accretion flows around compact objects, Flash Talk and Poster, GALFLOWS meeting, IUCAA, Pune, India., 2 – 5 February 2023.

Nishant Singh

Multi-scale Phenomenon on the Sun: Present capabilities and Future Challenges, talk on 3 April 2023 at USO-PRL, Udaipur Solar Observatory, Udaipur during 3-5 April 2023.

Magnetic Fields and Radiative Processes invited talk on 1st Nov 2022, Future of Indian Astronomy meeting, ICTS, Bangalore during 31 Oct-4 Nov 2022

Solar Magnetic Fields and Convective Conundrum invited talk, NCRA, Pune, 27 May 2022

Magnetic Field Evolution in Low Density or Strongly Stratified Plasmas, invited talk Nordita program, on 30 May 2022, 16 May-7 June 2022

MHD equations and the Solar Wind, invited talk on 25 Aug 2022 National workshop on CME Kinematics 2022 during 24 – 27 August 2022 organized from Centurian University of Technology and Management, Bhubaneswar (Online)

Talk at RRI, Bangalore, 18-22 July, and 21-27 August 2022

Raghunathan Srianand

Variation of constrant probed using QSO absorption lines, invited talk, workshop on "The constancy of the fundamental constants? IUCAA, Pune, 1 December 2022.

Extra-galactic astronomy in the era of ELTs, invited talk, Golden Jubilee celebration of Physics Department, Utkal University, Bhubaneswar, 2 January 2023.

Gas flows: As probed using quasar spectra, invited review talk, "GALFLOWS meeting" IUCAA, Pune, 2 February 2023.

Astronomy in the era of extremely large telescopes? the Regional Astronomy meet in Kochi, Kerala, 17 February 2023.

Kandaswamy Subramanian

Magnetic fields from the early universe, Astronomy seminar, ICTS-Bangalore (April 2022)

Measuring turbulent transport coefficients and their non-locality, Fluids, ICTS-Bangalore (April 2022)

Magnetizing the Universe, Physics Colloquium, Ashoka University, (September 2022)

Primordial Magnetic fields, Cosmology@CCSP, SGT University (October 2022)

Magnetizing the Universe, Nordita Niels Bohr Colloquium, Sweden, (October 2022)

Magnetic helicity fluxes from triple correlators and dynamical models of large-scale dynamos, Dynamo seminar, Nordita, Sweden (November 2022)

Primordial Magnetic fields, Cosmic Magnetism in Filaments and Voids, Bologna, Italy (January 2023)

Durgesh Tripathi

The Sun: Its hot atmosphere and its consequences, Agarkar Institute, Pune, 07 April 2022

Its hot, its magnetic, its happening and it matters: the solar atmosphere and solar wind, ARIES Colloquium, 17 May 2022

Doppler Shifts and Centre to Limb Variation in Transition Region, Durgesh Tripathi, Abhishek Rajhans, James Klimchuk, Oral Presentation, LOOPS workshop, Paris, 28 June to 01 July 2022

The Aditya-L1 Mission of the Indian Space Research Organization, Durgesh Tripathi and Aditya-L1 team, Invited Talk, IAU symposium on The Era of Multi-Messenger Solar Physics, 2-5 August 2023, Korea.

Durgesh Tripathi and Aditya-L1 team, Solicited Talk, Division E meeting, IAU General Assembly, Aug 2-11, 2022, Korea.

Introduction to Sun and Solar Flares, Invited talk, Aditya-L1 Support Cell Second workshop, Manipal Center for Natural Sciences, 27-30 November 2022

Public talk at Manipal Center for Natural Sciences, CNS on "The Fiery Star that Gives us Life", Nov 28th, 2022.

The Aditya-L1 mission of the Indian Space Science Research Organization (ISRO), Institute Colloquium, Astronomical Institute of the Romanian Academy, 16 November 2022.

Studying Aditya (the Sun) with Aditya-L1 mission of ISRO, Public AstroSat workshop, Goa University, 14 January 2023.

Introduction to Solar and Terrestrial Physics, talk during the IUCAA workshop on 'Sun and Space Weather impacts on terrestrial environment', 15-16 March 2023.

Introduction to Solar Flares, in the IUCAA workshop on 'Sun and Space Weather impacts on terrestrial environment', 15-16 March 2023.

(i) LECTURE COURSES

Debarati Chatterjee

Compact Stars I & II (2 lectures), IUCAA Introductory Summer School in Astronomy and Astrophysics and Refresher Course 2021, broadcast live on Youtube, 2 & 3 June, 2022

Gulab Chand Dewangan

X-ray astronomy (2 lectures), IUCAA Introductory Summer Scholl Summer School and Refresher Course at IUCAA, May – June 2022.

Dipanjan Mukherjee

Radiative Transfer (4 lectures) and *Computational Astrophysics* (1 lecture) in the IUCAA Summer School in A&A 2022.

Neeraj Gupta

ISM and Radio Astronomy (3 lectures), IUCAA Summer School (May - June, 2022)

Ranjan Gupta

Photometry and Spectroscopy, Delivered two talks during 16-17 May 2022 during the IUCAA Summer School (ISSAA 2022).

Shasvath J. Kapadia

Gravity and Black Hole, IIT Gandhinagar, 9-11th November 2022.

Testing Aspects of General Relativity-II, University of Lethbridge, IIIT Allahabad, and IIT Gandhinagar, 11th-13th April 2023. (online)

Aseem Paranjape

Structure formation in the Universe (4 lectures), IUCAA Summer School (May - June 2022)

Large-Scale Structure (4 lectures), ICTP Summer School on Cosmology, Trieste, Italy (July 2022)

Kanak Saha

Galaxies and dynamics (3 lectures) ISSAA 2022, IUCAA Pune, May, 2022

M.Sc. Astrophysics (15 lectures) Cooch Behar Panchanan Barma University, Cooch Behar, May 9 - June 10, 2022

Nishant Singh

Fluids and Plasma Physics (3 lectures), and Solar Physics (1 lecture), IUCAA Summer School/Refresher Course, during May – June 2022

(j) CO-HOST FOR LECTURES

T. P. Singh

Octonions, elementary particles, and the standard model Lecture Series 24 February – 15 December 2023 (online)

(k) POPULAR/PUBLIC LECTURES

Prakash Arumugasamy

Birth and death of stars, 'Science, Astronomy and Society,' Tata Institute of Social Sciences (TISS), Tuljapur, 3 December 2022.

Exoplanets, 'Science, Astronomy and Society,' Walchand College of Arts and Science, Solapur, 11 January 2023.

Debarati Chatterjee

Probing Extreme Physics with Gravitational Waves, Basic Astronomy Course organised by Jyotirvidya Parisanstha (JVP), April 20, 2022 (Online)

A new Era in Gravitational Wave astronomy with LIGO-India, Star-Fest, New Model Degree College, Hingoli, 5-6 Aug 2022

About LIGO-India (in Hindi), Toshniwal College of Arts, Science and Commerce in Sengaon, Hingoli, 6 Aug 2022

Public outreach talk (in Hindi), a school in Bhosi cluster in Aundha Naganath (Hingoli district), 6 Aug 2022

Building a Gravitational Wave Science Community in India, POEC session, 41st Meeting of the Astronomical Society of India, Indore, March 3, 2023

LIGO-India: A Gravitational Wave detector on Indian soil, Frontiers in Physics XVI, Fergusson College, Pune, April 12, 2023

Shasvath J. Kapadia

LIGO-India, EPO as part of the Listening to the Cosmos YouTube series

Sanjit Mitra

How to attract Women to Science?' Panel discussion and presentation, National Science Day celebration, IUCAA, Pune, 26 February 2023

Ranjeev Misra

X-ray Variability of Black Hole Systems: The AstroSat Advantage, colloquium at NRIAG, Cairo, Egypt, March 2023.

X-ray Variability of Black Hole Systems: The AstroSat Advantage,

Colloquium at RRI, Bangalore, June 2022.

Developing Diverse User Community:The AstroSat Experience, AstroSat 7th year Meeting, ISRO, Bangalore, September 2022.

Identifying the QPO frequencies of GRS 1915+105 as General Relativistic Dynamic ones, conference on "Growing black holes: accretion and mergers", Kathmandu, Nepal, May 2022

X-ray Binaries: A Review, at workshop "High Energy Astrophysics", Govt. Coll. Madappally, Kerala May 2022.

Anupreeta More

Discovery of Gravitational lens systems with Citizen Scientists, invited public talk, MGM Astronomy Meeting, Aurangabad, 6 May 2022

Beyond Solar System, invited public talk, Amravati Colleges, 2 October 2022 (Online)

T. P. Singh

Elementary particles, and the magic of the octonions, Frontiers in Physics XVI, Fergusson College, Pune April 11-12, 2023.

Pedagogical activities (Talks/Posters at conferences) by the Solar Group

Thermal and Non-thermal Energy Evolution in Solar Flares, in Hinode-15/IRIS-12 meeting at Astronomical Institute of the Czech Academy of Sciences, 19 to 23 September 2022. [Oral Presentation, Soumya Roy, K. Reeves, C. Moore, D. Tripathi]

Solar Ultraviolet Imaging Telescope (SUIT) Forward Modelling, in AGU fall meeting 2022, 02 to 16 December 2022. [Oral Presentation, Soumya Roy, Anusha, Bhasari, Veronika Witzke, Durgesh Tripathi,P. Sreejith, A N Ramprakash, Alexander Shapiro, Sami Solanki]

Thermodynamic Evolution of Plumes, 41st meeting of Astronomical Society of India held in IIT Indore from 01-05 March 2023. [Poster presentation, Biswanath Malaker, Durgesh Tripathi, Vishal Upendran]

Accelerating space weather forecasts with deep learning and interpretable A.I, SPARC workshop: Machine Learning in Solar Physics and Space Weather at IISER Kolkata 30 June 2022 [Oral Presentation: Vishal Upendran]

CosmicVarta: An initiative to take current Indian research to the public" Young Astronomers' meeting, ARIES Nainital: 9-13 November 2022 [Oral Presentation, Vishal Upendran]

From Sun to Earth using Interpretable A.I., Machine learning workshop at the Astronomical Society of India meeting at IIT Indore: 1-5 March 2023 [Oral Presentation: Vishal Upendran]

Tutorial on using spherical harmonics with data, Geospace Environment Modeling (GEM) summer workshop 2022 at Hawaii (Online talk): 11-16 June 2022 [Oral Presentation: Vishal Upendran]

Coronal heating in QS and Coronal holes, Loops 10 workshop at CUP Paris, France: 28 June – 1 July 2022 [Poster presentation, Vishal Upendran and Durgesh Tripathi]

Inferring quiet Sun heating using machine learning, Loops 10 workshop at CUP Paris, France: 28 June – 01 July 2022 [Oral Presentation, Vishal Upendran, Durgesh Tripathi, N.P.S. Mithun, Santosh Vadawale]

Accelerating astronomy workflow with deep learning and interpretable A.I., XXXI IAU General assembly: Symposium on Machine Learning in Astronomy at BEXCO, Busan, South Korea: 2-11 August 2022 [Oral Presentation, Vishal Upendran, Mark Cheung, Shravan Hanasoge, Ganapathy Krishnamurthi]

Exploring the formation of solar wind, switchbacks, and Quiet Sun heating, XXXI IAU General assembly: Symposium on The Era of Multi Messenger Solar Physics at BEXCO, Busan, South Korea: 02-11 August 2022 [Oral Presentation by Vishal Upendran and Durgesh Tripathi]

Flows in enthalpy-based thermal evolution of loops, Loops 10 workshop at CUP Paris, France: 28 June – 01 July 2022 [Oral Presentation, Abhishek Rajhans, Durgesh Tripathi, Stephen Bradshaw, Vinay Kashyap, and James Klimchuk]

Modeling of microflares observed by FOXSI and AIA: single power law distribution for background and transients, Loops 10 workshop at CUP Paris, France: 28 June – 01 July 2022, [Poster presentation, Abhishek Rajhans, Vinay Kashyap, Vishal Upendran, Durgesh Tripathi, and P.S. Athiray]

Optical Alignment and Imaging Performance of the Solar Ultraviolet Imaging Telescope (SUIT) onboard Aditya-L1, Astronomical Society of India meeting at IIT Indore: 01-05 March, 2023 [Oral Presentation, Janmejoy Sarkar, Ravi Kesharwani, Raja Bayanna, Melvin K. James, Soumya Roy, Sreejith Padinhatteeri, A.N. Ramaprakash, Durgesh Tripathi, Rushikesh Deogaonkar, Bhushan Joshi, Chaitanya V. Rajarshi, Deepa Modi, Nidhi Mehandiratta, Bhargavaram B. S., Mandeep Kiran, Vishweshwar Rao B., Venkateswaran R., Sankarasubramanian K., Nigar Shaji]

The Sun, Workshop on Beginning Astronomy: Start a data-driven journey, Manipal Academy of Higher Education from the 2-4 of February 2023 [Oral Presentation: Megha Anand]

SCIENTIFIC MEETINGS AND OTHER EVENTS

Indo-French School (IFAS7) on Spectroscopy and Spectrographs

The IFAS7 school gathered 20 student participants from different horizons to expose them to high-level specialized lectures and propose them to carry out an eight days long research project. The subject was "Spectroscopy and Spectrographs." It covered observational and data-reduction techniques through the source detection and extraction in integral-field spectroscopy, multi-wavelength photometry, and spectral energy distribution modelling. One of the major highlights of the IFAS school is its intense project-based research. The school was held during 21-27 November 2022. It was coordinated by Kanak Saha.

[For details, see Khagol, No. 130]

Constancy of the fundamental "constants?"

This meeting is the first one of its own kind has brought several Indian scientists working in different Physics fields to brainstorm on their common science goals. New ideas have nucleated from this meeting particularly the exchange of knowledge between the theorists and experimentalist/ observational groups, and inter-field collaboration shall open-up new possibilities to start complex experiments, writing joint proposals etc. The meeting was held on December 01-02, 2022, and coordinated by Subhadeep De and Sowgat Muzahid.

[For details, see Khagol, No. 130]

GEANT4 Physics Applications Workshop

A national workshop on GEANT4 and its Application to High-Energy Physics and Astrophysics, jointly organised by TIFR and IUCAA, was held at IUCAA from 5th to 9th December 2022. GEANT4 is a toolkit to simulate particle (or radiation) interactions with matter as they pass through it. It is primarily used to simulate detector physics and response in high-energy physics as well as high-energy astrophysics. The aim of the workshop was to bring together the GEANT4 user community in India and introduce intermediate to advanced concepts of GEANT4 to graduate students, postdocs and scientific staff who use GEANT4 in their research work. The workshop was coordinated jointly by Gulab Dewangan and Shriharsh Tendulkar (DAA, TIFR).

[For details, see Khagol, No. 130]

IUCAA - NCRA Radio Astronomy Winter School - 2022

IUCAA and NCRA–TIFR jointly conducted the 15th Radio Astronomy Winter School 2022 from 13 December 2022 to 23 December 2022. Since 2019, the Teaching Learning Center of IUCAA has been organizing the school, adopting a teaching-learning model. In this model, college and university faculty members were invited to mentor the student groups formed for the school's activities. This year, five faculty members were invited and 27 student participants out of 665 applicants were selected. The Winter School was coordinated by Prakash Arumugasamy, Jameer Manur and| Subhashis Roy (NCRA, Pune).

[For details, see Khagol, No. 130]

The Cosmic Crowd in the Universe

The Inter-University Centre for Astronomy and Astrophysics (IUCAA) organized a one-day symposium titled "The Cosmic Crowd in the Universe" on December 19, 2022. The symposium was aimed to provide a platform for researchers to discuss the status and understanding of the various astrophysical processes inside the densest environment of the universe and pay tribute to eminent astronomer Somak Raychaudhury for his immense contribution to the field. The symposium was coordinated by Kanak Saha, Ranjeev Misra and Tarun Deep Saini (IISc, Bangalore).

[For details, see Khagol, No. 130]

Foundation Day 2022

The 34th IUCAA Foundation Day Lecture was delivered by Professor Satishchandra B. Ogale on Thursday, 29 December 2022. Professor Ogale, in his talk titled ***Building a Sustainable Future: Complex Problems in Search of Pragmatic Innovations***, highlighted that energy, environment, and health are the most concerning topics for the whole world at this time, given their direct implications for the long-term sustainability of the civilization on this

planet. The three topics are not only intertwined with one another in very complex ways but also have an intrinsically global character in terms of their canvas and connectivity. The lecture ended with a lively discussion with the audience as well as questions taken online over YouTube and passed on to the speaker. The recorded lecture is available at the YouTube link: https://www.youtube.com/live/apabU_5_Nug?feature=share.

[For details, see Khagol, No. 130]

National Workshop on Galactic inflows and outflows on all Scales (GALFLOWS)

A national workshop on Galactic inflows and outflows on all Scales (GALFLOWS 2023) was jointly organised by IUCAA and NCRA, at IUCAA from February 02-05, 2023. The workshop brought together researchers in India working on the topic of gas flows in and around galaxies on varying spatial scales. The workshop, a first of its kind on this theme of astrophysics in India, was attended by more than 60 participants with about 40 contributed talks and 17 invited speakers. The review and contributed talks gave a well-rounded highlight on the current trends of research in the national and international arena, both in observational and theoretical topics, and highlighted the pathways to follow in future in view of upcoming international projects. The workshop was coordinated by Dipanjan Mukherjee and Sowgat Muzahid.

[For details, see Khagol, No. 130]

PUBLIC OUTREACH HIGHLIGHTS

SPECIAL EVENTS

Partial Solar Eclipse Event - 25th October

A partial Solar Eclipse was observed on 25th October from almost all parts of India.

i. At IUCAA, Pune: IUCAA conducted a huge Eclipse viewing program in collaboration with CSEC where 4 telescopes with solar filters were set up. More than 1000 people visited to observe the eclipse through telescopes. Solar filter goggles were also provided at the venues. The Scipop team members Tushar Purohit, Mayuri Patwardhan, Maharudra Mate, Emma Chokar, and Atharva Pathak coordinated the event.

ii. At Guhagar, Konkan: Similar eclipse viewing program was conducted on the beach, at Guhagar located near Ratnagiri. As the eclipse was taking place almost near the sunset timings, the sun was visible without any obstruction near the sea and people could view it till 6:05 pm. One telescope was set up with a solar filter and solar goggles were provided at the venue. More than 150 people attended the event. The event was coordinated by Shivani Pethe.

iii. Similar viewing was done at Lonar by Samir Dhurde and at Pargaon (Ambegaon Taluka) by Rupesh Labade. 120 people attended the event. Solar Eclipse from all these sites was live streamed on the IUCAA YouTube channel.

GlobalSCAPE international events

As part of the advisory board of the EU-funded GlobalSCAPE project, Samir Dhurde was part of the design of some Science Communication training modules and open-access workshop materials for sci comm practitioners during 2021-22.

A one-day skill-building session aimed at science communicators was delivered at IUCAA on 25 November 2022. It was organized in collaboration with Springer Nature, as part of the GlobalSCAPE consortium. This was part of a series of workshops in six different locations around the world: Spain, South Africa, Australia, India, Colombia, and Japan. The speakers were Shubhra Priyadarshini, from Springer Nature India and Samir Dhurde. The workshop was attended by 22 science communicators from across the country.

As part of the final event of the GlobalSCAPE project on 03 February 2023, Samir Dhurde gave a talk about IUCAA activities and how to keep outreach low-cost and local, in Brussels, Belgium.

Science toys demonstration, Telescope Making, Astronomy, and Skywatch events:

1. Science Toys / Experiment Demonstrations were conducted at Radhabai Kale Mahila Mahavidyalaya, Ahmednagar a two-hour Science experiment demonstration was given on 10th October 2022, 120 Girl students of BSc attended this session.

2. Science Toys Demonstrations at KTHM college, Nashik was attended by 80 B.Sc. and M.Sc. students who attended this session on 15th October 2022.

3. Telescope and Science toy-making session was organized at the Center for Cosmology and Science Popularisation (CCSP), SGT University, Haryana. A two-day session was attended by 30 students of B.Sc. Physics from 7 - 9 November 2022.

4. School Students Science Toys Workshop was organized at iTeach Pandit Deendayal

Upadhyay School, Kothrud, Pune on 30 November 2022. 80 school students attended this activity.

5. SPPU CSEC arranged a Science Workshop and Hands-on Toys activities on 20 December 2022 for students from CSEC, SPPU. This was held at IUCAA MVS campus.40 students with their parents attended this workshop.

6. A visit and Science workshop were organized at MVS on 21 December 2022. Science Toys Demonstration was conducted for 41 MSc students from the P. D. Patel Institute of Applied Sciences, Gujarat.

7. The science toys Demo and the skywatching event were held at Samarth College of Engineering on the occasion of the Junnar Taluka Science Exhibition on 29 December 2022. A total of 800 school and college students attended these sessions.

8. Science Demo and Skywatch session at R D Oswal school, Triputi was conducted for 600 students of 6th to 10th standard and parents on 30 December 2022.

9. Science Toys session at Chincholi Kashid, Junnar - Monday, 02 January 2023. This was a rural outreach event for 90 school students and 06 teachers from the Samarth Madhukarrao Vidyalaya, Chincholi, Kashid.

10. Sky Observation event at Pandit Jawaharlal Nehru Vidyalaya, Nirgudsar 04 January 2023. Science toy demonstrations and a night sky observation program were conducted for 700 school students, their parents, and schoolteachers. A total of 900 people attended the session.

11. Khed taluka Science exhibition - 06 January 2023. Science Toys demonstration session was held at the Khed taluka science exhibition organized at Gladiolus English Medium School, Khed, A total of 400 students attended the session.

12. Science Toys demo for Eureka Science Centre, Pune - 23 January. 24 students and 04 teachers visited MVS and attended the session.

13. Volunteers Training at Ruia College was conducted on 29 January 2023. 20 students from MSc. participated in the session. Different science toys were made by the students which then they used as teaching aids in school sessions. A talk was also conducted before the session on science communication as a career option and basic astronomy on 14 December 2022.

14. Science Toys demonstration session was arranged at Vidya Vikas Mandir School, Karandi Village on Monday, 30 January. The session was organized by NSS camp students from the Gokhale Institute of Technology, Pune. 60 school students attended this session.

15. Science Toys Workshop for underprivileged children was conducted at Wadala, Mumbai on 7 February. Around 25 students from classes 8 to 10 attended the demonstration session.

16. Thursday workshops at MVS, IUCAA: A Science immersion workshop was arranged for the iTeach PCMC English Medium School on 16 March. 84 students and 05 teachers attended the workshop.

17. Demo sessions at Rayat Shikshan Sanstha, Satara, 28 – 29 March 2023: A two-day

Science and Astronomy demonstration session was organized at the campus of the Rayat Shikshan Sanstha, Satara by DIET, Phaltan. 300 students from classes 8 to 11 attended the hands-on workshop.

*The above sessions were conducted by Rupesh Labade, Tushar Purohit, Maharudra Mate, Mayuri Patwardhan, and Shivani Pethe from the IUCAA Scipop Team.

"Exploratory Science Sessions" at Prajna Prabodhan Varg, Jnana Prabodhini - held from October to December 2022

A three-month program from October to December 2022, was held in Jnana Prabodhini for the students of Prajna Prabodhan Varg. This program's main focus was learning physics and astronomy concepts through hands-on training. These Exploratory Science Sessions were conducted in Jnana Prabodhini's campus, where Shivani Pethe, Rupesh Labade, Atharva Pathak, and Mayuri Patwardhan conducted a total of 10 sessions which included topics from physics like light, sound, and magnetism and astronomy topics like astrobiology. These sessions also included out-of-the-box topics like apps that can help students to learn various concepts in science and astronomy. A total of 42 students attended this program where a lot of hands-on activities and lab sessions were included for better experience and understanding of the concepts. These students also visited the IUCAA campus for one of the sessions on light and had a guided visit to the IUCAA Campus.

These Exploratory Science Experiential Learning sessions were coordinated by Shivani Pethe.

TEACHER TRAINING PROGRAMMES

1. Teachers training in Hingoli – 01 October 2022
   The IUCAA Scipop team organized a one-day teachers training for Zilla Parishad School Teachers of the Hingoli district at New Model Degree College, Hingoli. 75 Teachers from the Hingoli district attended this training. The training was based on scientific toy making and the basics of Astronomy.

2. Astronomers Meeting at SRTMU, Nanded - 02 October 2022
   Astronomers from Parbhani, Hingoli, Nanded, and around were gathered together at SRTMU, Nanded for discussion about Astronomy outreach around the LIGO-India project site.20 Astronomy enthusiasts attended this meeting and had an innovative discussion on improvement for science popularization.

3. SKA Outreach and Radio Kit Inauguration (11 – 12 November 2022)
   A two-day Teachers Training for Teachers from Ambegaon and Junnar taluka was organized at the IUCAA campus. 30 teachers participated in the program. Themes like NCRA campus visit, basics of radio astronomy, and information about Radio Astronomy kit were included in this training.

4. Teachers training at Hingoli (22 November 2022 and 23 December 2022)
   80 Zilla Parishad Teachers from Hingoli District attended this one-day training on 22nd November 2022. On 23 December 2022, 60 ZP Teachers from Hingoli District attended this training. Both the training sessions were based on basic concepts in science.

5. PKC STEM teachers training workshop - (7-8 December 2022)
   40 Teachers enrolled for a day-long Astronomy hands-on session at IUCAA which was jointly organized by Pune Knowledge Cluster (PKC) and the IUCAA Scipop team.

SKA-India outreach RRI, Bangalore & Gauribidanur Observatory: (16 – 20 January 2023)

A week-long outreach program that involved talks, kit demonstrations, and Teachers Training was organized in collaboration with Raman Research Institute (RRI) and the Indian Institute of Astrophysics (IIA), Bangalore. To start with Samir Dhurde, Shivani Pethe, and Rupesh Labade had an interaction at the Indian Institute of Science (IISc) on 17 January 2023 followed by a talk at IIA with an experimental optics demonstration conducted for 40 students and faculty on 18 January 2023. This was followed by a day-long teachers' training at the Gauribidanur Radio Observatory on 19 January, which witnessed the participation of 40 teachers from rural schools near Gauribidanur. A guest lecture was delivered by Prof. Prajwal Shastri, along with interactions with researchers from RRI & IIA.

NATIONAL SCIENCE DAY 2023

After a gap of two years, the IUCAA National Science Day celebrations were back this year in the in-person format. Taking advantage of the Sunday just two days prior to the science day an open day was conducted on 26th February 2023. The programs also continued on the National Science Day i.e. 28th February 2023.

The two-day celebrations of National Science Day attracted numerous groups of students along with teachers, parents, and the public, who came from around Pune and other parts of Maharashtra. Like every year, IUCAA observed the enthusiasm of people to associate better with Science and Scientists. Following are the details of the exhibits and interactive programmes conducted over the course of the

two days.

The main attraction of the National Science Day 2023 celebrations was the models of Aditya L1 and JWST's Unfolding model. There were posters regarding the same at Bhaskara 2 and Sky Dome respectively. There were demonstrations about Gravitational Waves, Black Holes, and Laser Interferometers at Bhaskara 2. The whole campus of IUCAA including the MVS and TLC building and the area near Chandrasekhar Auditorium was covered with models and posters. A number of spectacular posters designed and presented enthusiastically by research scholars of IUCAA were displayed, which made the people aware of the ongoing research and new developments in the subject.

Themed videos were streamed on "Astronomy in Space" at Bhaskara 1. The Solar Ultraviolet Imaging Telescope models and demonstrations were ongoing in Bhaskar 3. Near the new TLC building, we had some Radio Astronomy experiment exhibits and posters. There was a set of four posters and exhibits on the 'Life cycle of a Star' near the Chandrasekhar auditorium which was enjoyed the most by the school students. Apart from these, the Foucault pendulum, the statues of great scientists on the campus, short interactive sessions on Aditya L1, the Live Solar telescope, and the Sun & Solar Astronomy exhibit pulled a large number of people.

Short talks on Reasons for Seasons, Cosmic Zoom, and My Life as an Astronomer, were delivered by Moupiya Maji & the IUCAA OAE Team, Samir Dhurde, Megha Anand, and Divya Rana respectively, which kept the audience rooted in the Chandrasekhar Auditorium during the morning session.

In the afternoon, there was a live interaction with Raghunathan Srianand, Ajit Kembhavi, and Jayant Narlikar, who eloquently answered several astronomy-related questions from the public. This was coordinated by Surhud More. Most of the wonderful questions regarding our universe came forward from young school kids. Following this, there was a special panel discussion on 'Inspiring the future women of science'. Panel members included Manasadevi P T, Anupreeta More, Debarati Chatterjee, Sukanya Mallik, Sanjit Mitra, Siddharth Maharana & Vishal Upendran. Many girls schools from Pune attended this session. This was followed by an interesting talk on 'Astro MythBusters'.

On the evening of February 26, a public interaction titled: Studying the Sun with Aditya-L1, was delivered by Helen Mason, Durgesh Tripathi, and Nishant Singh. The interaction was moderated by Samir Dhurde. Close to 7,000 people visited IUCAA in these two days, and approximately 2,500 odd people attended the sky-watching sessions.

As per the tradition, there were events for school students prior to the open day. IUCAA Public Outreach personnel conducted a science quiz, along with essay writing, and drawing competitions for the rural students of the Ambegaon taluka on 11 February 2023. Vaidehi Paliya, Sudhir Gholap, Atharva Zend, Shivraj Kandasamy, and the Scipop Team (all from IUCAA) enthusiastically encouraged the students from 15 rural schools, who competed at the venue generously provided by the Government Polytechnic, Awasari.

On February 25, 2023, about 180 students from 36 schools in Pune City responded to IUCAA's invitation and participated in another set of inter-school competitions. Students from classes VIII to X took part in drawing, essay, model making, and science quiz competitions. During the first round of the quiz, Prof Surhud More gave an interesting talk to the teachers, who accompanied the students. After the finals of the quiz competition, all winning students received their prizes from R. Srianand (Director, IUCAA) and Nishant Singh, which included the students from the rural schools, who were specially invited to IUCAA for a visit that day. All the students were very happy to have a chance to interact with the IUCAA scientists during these National Science Day celebrations.

Shortlisted models made by school students on the theme, 'Science from Kitchen', chosen by coordinators, Manasadevi P. T, Shivraj Kandhasamy, and Nishant Singh were exhibited on National Science Day for the visitors. The final judging was also done on the same day.

All the public talks and the Ask a Scientist session were streamed live and are available at: **https://www.youtube.com/iucaascipop.**

Ph.D. DEGREES AWARDED

PH. D. PROGRAMME

During the year of this report, seven IUCAA Research Scholars have defended Ph.D. theses, namely: **Sorabh Chhabra** [Guide: A. N. Ramaprakash], **Rajorshi Chandra** [Guide: Tarun Souradeep], **Siddharth Maharana** [Guide: A. N. Ramaprakash], **Vaishak Prasad** [Guide: Sukanta Bose], **Abhishek Rajhans** [Guide: Durgesh Tripathi], **Prakash Tripathi** [Prof. Gulab Dewangan] and **Vishal Upendran** [Guide: Durgesh Tripathi]. Their Ph.D. degrees have been awarded by the Jawaharlal Nehru University, New Delhi.

The synopses of their theses are given below :

Sorabh Chhabra

A new memory principle-based speckle correlation imaging technique through atmospheric turbulence

Focusing light through thick or thin scattering layers of random media in an optical regime is burdensome. When an incident ray of light penetrates a non-absorbing opaque medium such as living tissue, atmospheric turbulence, fog etc., randomization starts happening to it due to scattering phenomena. Therefore, the exited beam displays are too convolved to produce any observable optical image. This scattering is the major source of random noise that poses a primary scientific challenge in diverse application areas, particularly in biomedical imaging, astronomical imaging, photonic crystal fabrication, applications related to remote-sensing, etc. Inhomogeneities in the refractive indices remodel any input optical field data into arbitrary variations of bright and dark spots called speckles. The information available at the far-field detection plane is a low-contrast, random, and obscure information image. Speckle effects cannot be foreseen due to inhomogeneities. But can be taken down using advanced modern techniques. The final grainy structure at the detector plane encodes enough information of scattering medium, but the unique problem lies in the characterization job of the scattering medium. Characterization of scattering medium helps determine the medium's power spectrum of speckle noises fine features. Due to fast random variations of the medium, dynamic, real-time characterization will often be required. Applications in astronomical imaging, including adaptive optics and speckle interferometry, help overcome this effect, at least to some extent. Image retrieval through atmospheric turbulence is far less difficult than through other diffusing mediums like biological tissues, where the degree of distortion is much more significant. Methods dealing with speckle-noise reduction covering various applications are explained in chapter 1.

The advent of large aperture telescopes bring the capability to gather a large number of photons. However, atmospheric turbulence can often diminish the resolving power of the 10 m telescope to that of a 10 cm telescope. In the early 1920s, Michelson was the first who came up with the idea of interferometry and helped limit distortion due to atmosphere. Later in 1940s, radio interferometry adopted this approach and brought down a resolution from 1 arcsec to 0.001 arcsec. A very short exposure image at the focus of any telescope contains many short-lived speckles. This is due to the effect of the interference of light coming from small sub-apertures of the telescope. J.Texereau (1963) was one of the first who correctly described the speckle phenomena in his study of the image quality limitations in large telescopes. J.Texereau (1963) successfully resolve binary stars separations and angles between them using sensitive photometric films at the focus of a 1.93 m telescope. However, he did this without employing speckle interferometry technique. In 1970, A. Labeyrie was the first to point out that a speckle image contains information of objects up to the telescope's diffraction limit. It became a widely accepted technique in astronomical imaging and termed speckle interferometry. In Chapter 1, we have covered basic speckle phenomena, shortfalls and future requirements, phase retrieval algorithms and the working of a state of the art instrument.

This thesis presents a new memory-based speckle imaging technique through atmospheric turbulence. Chapter 2 introduces a improved technique for generating accurate FFT based atmospheric phase screen simulations. Chapter 3 covers 3D models for speckle imaging through multilayer atmosphere and the development of speckle imaging technique code for complex object recovery. Chapter 4 covers the design and development of an laboratory instrument called SIMULATOR, a speckle imager. Chapter 5 covers some aspects of the commissioning of an instrument called RoboAO on the 2 m class IUCAA Girawali Observatory (IGO) telescope.
The purpose of adaptive optics and any other similar technique is to overcome the effect of atmospheric turbulence. Adaptive optics implements real-time sensing and correction of atmospheric induced distortions. However, post-processing techniques focus on analyzing the data later. Chapter 2 includes important turbulent characteristics like power spectrum, velocity and temperature fluctuations, wind profile etc. To account for point sources characteristics through turbulence medium either its infinite distance away or resides at a certain altitude, wave propagation needs to be investigated in detail which is covered in the remaining part of chapter 2.

Accurately simulating the atmospheric turbulence behaviour is well recognized as very challenging. For a variety of purposes such as the design and development of adaptive optics systems, speckle imaging techniques, atmospheric propagation studies etc., it is essential to simulate good atmospheric phase screen models. Methods based on Zernike polynomial expansions FFT-based methods,Low Frequency Optimization method etc. have been in use for this purpose. The Zernike polynomial method, which is widely in use, has a limitation due to the maximum number of coefficients needed for accurate compensation. The optimization method which compensates accurately for low frequency part of the spectrum by using unequal sampling and unequal weight in low frequency region, does not cover high frequency deficiencies. Among these, FFT-based methods are computer memory size friendly and widely accepted. But, FFT operators assume uniform sampling for the non-uniformly distributed phase power spectrum which can lead to underestimation in the low and high frequency out of band regions. Thus, it has limitations in recreating the true phase power spectrum. To compensate for low-frequency components, Johansson and Gavel suggested employing the modified subharmonics equation (an adaptation from Lane et al. which works well up to an infinite outer scale length. Sedmak later compared the performance of this method with that of Lane et al. by actually calculating the phase structure function from the simulated screen. He improved upon Lane et al. by employing different fine tuned subharmonic weights for different G/L_0 ratios. Results from his analysis show that these FFT-based simulations are accurate for large screen size (G) to outer scale parameter (L_0) ratios. For a screen size of $G = 200$ m and outer scale of $L_0 = 25$ m, the maximum relative error in the simulation approaches 1%. Our simulations demonstrate that the errors from low-frequency components start shooting up once we move to smaller G/L_0 ratios, even after compensating with modified subharmonics. In chapter 2, we have modified the subharmonics based approach by introducing a Gaussian phase autocorrelation matrix that compensates for these shortfalls. We show that the maximum relative error in structure function with respect to theoretical value is as small as 0.5-3% for (G/L_0) ratio of 1/1000 even for screen sizes up to 100 m diameter.

The atmosphere turbulence has constantly challenged optical band imaging in astronomy. Adaptive Optics (AO), which has been in use for the last half-century, is not only a sophisticated but an expensive technique. It can only correct limited order of Zernike modes. The achieved Strehl ratio lies in the range of 0.3-0.5 for bright stars in J-band. Lucky imaging is another technique practised in astronomy to obtain diffraction-limited results. However, it is only effective for $D/r_0 < 7$. For $D/r_0 > 7$, the probability to get short exposure images with strehl ratio ≥ 0.37 is almost close to zero ($\leqslant 10^{-6}$). Practically, Lucky imaging is limited for telescopes up to 2.5 m aperture. Medium and large scale telescopes, which will have $D/r_0 \gg 1$, will require many sophisticated techniques like Multi-Conjugated Adaptive Optics (MCAO), which increases complexity many folds.

Lebeyrie's work on speckle images, which he realized in the 1970s, extracts high-resolution information from the grainy data. Due to the non-availability of large aperture telescope and EMCCD's at that time, he was

only able to see stars brighter than 7 magnitude, and distinguishing fainter stars with sky background was an impossible task. The breakthrough work by Katz et al. (originally by Bertolotti) was a definite gamechanger. He cleverly exploits concepts suggested by J. C. Dainty in 'stellar speckle interferometry'. With the help of the 'angular memory principle,' he achieved diffractionlimited results with a single shot speckle image without knowing the exact scattering properties of the medium. We knew that speckle image reconstruction could correct up to infinite order of equivalent zernike modes. So speckle correlation-based imaging can overtake AO/Lucky imaging for upcoming large scale telescope with almost no added complexity to the future telescope.

In Chapter 3, we have followed work done by J. C. Dainty in 'stellar speckle interferometry' to obtain diffraction-limited results for giant aperture telescope. We have simulated speckle images for 3 m class and larger telescope. We validated our approach via autocorrelation of speckle field, against various sky background, read noise, and telescope reflectivity. A limited bandwidth source has been simulated and tested against diverse sky background and detector noises. An accurate hybrid Bispectrum-Fienup algorithm approach has been developed to recover lost phase and amplitude information in the space domain.

So far, we have discussed theory and simulation work related to the speckle-based interferometry technique. To give concrete evidence that this technique can be used at real astronomical observatories as a replacement for adaptive optics, we have deveeloped a lab test bench called SIMULATOR. **SIMULATOR** stands for **S**peckle **I**mager via **MU**lti **L**ayer **A**tmospheric **T**urbulence **O**bject **R** econstructor. It is a speckle imager that can mimic the characteristics of various observatory sites. This has been developed with the sole purpose of using post-processing techniques in image reconstruction under diverse conditions, including telescope site turbulence strength, wind profiles, sky background variations etc. The idea of this instrument was inspired by the MAPS (MultiAtmospheric Phase screens and Stars) instrument, developed under the ESO VLT team, to test the Multi-conjugate Adaptive optics project. With this instrument in hand, we can avoid the time request for a telescope which is extremely hard to get during these days. We can even test against different instrument errors too. This project aims to mimic the three-dimensional evolving turbulence effect, thus stimulating turbulence behaviour of the atmosphere, covering all layers of the atmosphere up to 83 km. Chapter 4 covers design and development of SIMULATOR. This includes Zemax optical design, procurement jobs, optomechanical design , assembling and testing etc.

Robotic adaptive optics (RoboAO) is a first fully autonomous adaptive optics system developed for 2-m class IUCAA Girawali Observatory (IGO). First version of this instrument was developed for Palomar observatory 60-inch telescope, USA. After successful installation of RoboAO at main cassegrain focus, 10W laser at side port and including rest of the electronics, the first observation was tried on UV sensing arm. Chapter 5 will cover part of my PhD work at the observatory, i.e. calibration of UV sensing arm

Rajorshi Chandra

Precision Cosmology from Cosmic Microwave Background Weak Lensing

Cosmology in the last few decades has become an extremely powerful field of physical information and scientific inquiry. The success of the standard model of cosmology has been consistent with multi generation experiments and it has now moved to the realm of precision physics, especially with the ΛCDM model and its parameter estimation inferred, in particular, from Planck data Observations of the cosmic microwave background play a large role in performing such analyses. There are many aspects of precision analysis that are incomplete, suboptimal or that remain relatively unexplored, especially with respect to upcoming experiments. This naturally provides us a powerful motivation to probe specific aspects of high precision cosmology and find ways to extract new or more precise physical information from cutting edge data and verify new models or address existing challenges in the ΛCDM.

A particular aspect important to precision cosmology from the CMB is the effect of weak lensing of the CMB anisotropies. Weak lensing forms both as a contamination that obscures underlying cosmological information and as a physical window carrying information itself. While the phenomenon and physics of weak lensing is well understood based on general relativity, the initial conditions and primordial fluctuations that led to the matter distribution that produce such lensing potentials, are still an active area of study. Tightly constraining weak lensing observables such as the CMB weak lensing power spectrum, are important in extracting estimates of parameters of interest. This naturally calls for both high precision lensing reconstruction techniques, as well inferencing tools that can extract key parameters of interest from such observables.

In addition the effects of weak lensing usually play a secondary role in noising or blurring underlying cosmological information, cause effects such as conversion of E mode polarisation power to B mode polarisation power of the CMB polarisation fields and damp the acoustic peaks of the CMB temperature power spectrum. Hence a thorough understanding of weak lensing as well as delensing formalisms are required to clean such contamination before further analysis.
In this thesis we tackle three projects from this context, which are related to each other successively. The first project addresses the primary challenge of reconstructing the weak lensing field and power spectrum from the observed temperature anisotropy map itself. We re-derive the state of the art minimum variance quadratic estimator with the Wiener filter and correction of weak lensing power spectrum biases due to non-Gaussianity introduced by lensing, in the BipoSH representation and write a estimation program to measure it from simulated data.

The second project builds a formalism where an estimation algorithm known as the Richardson-Lucy deconvolution algorithm is applied to weak lensing power spectrum reconstructed in the previous project, in order to extract information about the primordial scalar fluctuations during inflation in the form of the Primordial Power Spectrum. The third project approaches the weak lensing effect as a contaminant to the analysis of the CMB temperature anisotropy power spectrum, and we formulate a cleaning algorithm applied to the temperature power spectrum while reconstructing the free form power spectrum of the primordial fluctuations from it. This involves modifying the Richardson-Lucy deconvolution algorithm to include a non-linear transfer kernel as produced by weak lensing, in order to increase the estimator fidelity.

Siddharth Maharana

Design and Development Of Wide-Field Linear Optical Polarimeters (WALOP) for PASIPHAE Sky Survey

The work presented in this thesis aims at the design, development, performance modelling and calibration of two wide-field linear optical polarimeters, currently under development at the Inter-University Center for Astronomy and Astrophysics (IUCAA). Named as Wide-Area Linear Optical Polarimeter (WALOP), these will be used as survey instruments to carry out the Polar-Areas Stellar-Imaging in Polarization High-Accuracy Experiment (PASIPHAE) program and create the first large optopolarimetric map of the sky (greater than 1000 square degrees) at high Galactic latitudes. Using the WALOP-South and WALOP-North instruments, the survey will be carried out from the 1m telescope at South African Astronomical Observatory's (SAAO) Sutherland Observatory and the 1.3m telescope at Skinakas Observatory, Greece, in the southern and northern hemispheres, respectively. The optopolarimetric map will enable astronomers to probe many open questions related to the physics of dust and magnetic fields in the inter-stellar medium.

The WALOPs will be the first wide-field optical polarimeters, with a field of view (FoV) of 0.25 square degrees. They are being designed to measure polarization with accuracy of of 0.1 percent across the entire FoV in the R broadband filter. The design and development of these polarimeters presents a novel challenge, owing to their unique combinations of wide-field and high accuracy polarimetry- a kind of instrument which has thus far not been developed in astronomy. Through the work in this thesis, we present these challenges and our attempt in understanding and solving them in order to achieve the design goals for the instruments.

In Chapter 1, the basic ideas and concepts used in present day optical polarimetry are presented along with a short primer on the topics of Stokes parameters, Mueller matrices, and modern polarimeter design and operations. In the later part of this chapter, we present an overview of the PASIPHAE survey.

Chapter 2 details the complete optical design of the WALOP-South and WALOP-North instruments: the main challenges in creating the optical design of the instruments as well as the ways in which these were overcome. The design of WALOP-South was created first and was used as a baseline and modified to create the optical design of WALOP-North instrument. The complete optical design of the WALOP-South instrument is published as a paper titled *WALOP-South: a four-camera one-shot imaging polarimeter for PASIPHAE survey. Paper I—optical design*,Maharana et al., 2021.

In Chapter 3, the polarimetric modelling of the WALOP-South instrument is described with careful modelling and characterization of the sources of instrumental polarization. A methodology is presented to calibrate the instrument on-sky to obtain 0.1 percent polarimetric measurement accuracy. A paper outlining this entire work is ready to be submitted for peer review and is *WALOP-South: a four-camera one-shot imaging polarimeter for PASIPHAE survey. Paper II— Polarimetric Modelling and Calibration*, Maharana et al. Additionally, as part of the calibration method, we have proposed that the sky polarization within $\pm$ 2 days of the Full Moon can be used as a polarimetric flat source for calibration of wide-field polarimeters, and has been verified with observations. A paper containing the observations and results is in preparation.

In Chapter 4, we present the complete optomechanical design of the WALOP-South instrument. Finite Element Analysis (FEA) simulations were done to design the optics mounts and overall instrument model. Careful at-

tention was given to issues such as instrument flexure, stray light control, stress birefringence in optics- these are all effects that can lead to erroneous and inaccurate polarimetric measurements. The preliminary design of the instrument was presented as a SPIE proceedings paper-*WALOP-South:A wide-field one-shot linear optical polarimeter for PASIPHAE survey*, Maharana et al., 2020.

A major problem in optical polarimetry community is the dearth of stable and reliable standard stars to calibrate polarimeters on sky. As we head to the era of large polarimetric surveys, it is absolutely essential to have a large catalog of reliable polarimetric standards on sky. As presented in Chapter 5, to address this problem, since 2016, we have started an observational campaign to monitor 120 candidate standards. Over the years, we have obtained high cadence data from multiple telescopes. The details of the candidates, observations, preliminary analysis and results are presented.

In addition to the above, I have contributed to the following works, which are not part of this thesis report: (a) optomechanical design of the WALOP-North instrument, (b) optical design of WALOP-North guider camera, (c) observations with the Robert Stobie Spectrograph on the South African Large Telescope in imaging polarimetry mode with multiple narrow band filters to map the magnetic field structure around a young star in the Musca molecular cloud, (d) development of the point-spread function (PSF) photometry pipeline for the WALOP-South instrument based on simulated PSFs generated from the optical model of the instrument, and (e) work on RoboPol instrument performance characterization.

Vaishak Prasad

Strong gravity physics of dynamical horizons in black hole mergers and its imprint in their gravitational radiation

In a binary black hole merger, it is known that the inspiral portion of the gravitational waveform from two distinct horizons orbiting each other, and the merger and ringdown signals, correspond to the final horizon being formed and settling down to equilibrium. However, we still lack a detailed understanding of the relation between the horizon geometry in these three regimes and the observed waveform. Here, in this thesis, after some preliminaries in the first two chapters (i.e. Chapter 1, and Chapter 2, we show in Chapter 3 that the well-known inspiral chirp waveform has a clear counterpart on black hole horizons, namely, the shear of the outgoing null rays at the horizon. We demonstrate that the shear behaves very much like a compact binary coalescence waveform with increasing frequency and amplitude. Furthermore, the parameters of the system estimated from the horizon agree with those estimated from the waveform. This implies that even though black hole horizons are causally disconnected from us, assuming general relativity to be true, we can potentially infer some of their detailed properties from gravitational wave observations.

An important physical phenomenon that manifests itself during the inspiral of two orbiting compact objects is the tidal deformation of each under the gravitational influence of its companion. In the case of binary neutron star mergers, this tidal deformation and the associated Love numbers have been used to probe properties of dense matter and the nuclear equation of state. Non-spinning black holes on the other hand have a vanishing (field) tidal Love number in General Relativity. This pertains to the deformation of the asymptotic gravitational field. In certain cases, especially in the late stages of the inspiral phase when the black holes get close to each other, the *source* multipole moments might be more relevant in probing their properties and the No-Hair conjec-

ture; contrastingly, these Love numbers do *not* vanish. In Chapter 4, we track the source multipole moments in simulations of several binary black hole mergers and calculate these Love numbers for axisymmetric modes. We present evidence that, at least for modest mass ratios, the behaviour of the source multipole moments is Universal.

In the next part of the study, Chapter 5, we uncover new features in the source multipole moments of the dynamical horizons in binary black hole mergers. We extend the previous study of the axisymmetric multipole moments and compute and analyse the non-axisymmetric moments. We show that the dynamical horizons encode detailed information about the dynamics of the binary black hole system. Additionally, the source multipole moments of the dynamical horizon are shown to be strongly correlated with the gravitational field at null infinity. Therefore the gravitational waves carried away from the system contain important information about the geometrical structure of the dynamical horizons in the strong field regime.

The final leg of the thesis, (Chapter 6), deals with a survey and analysis of the possibility of extending the new and important results found in the inspiral phase to the ringdown phase. We analyse the outer common dynamical horizon of the binary black hole system formed during the merger and study its dynamics and relationship with the outgoing gravitational waves from the system. While we also find that the gravitational field at the common dynamical horizon shares a similar multipolar structure as that at the future null infinity $\mathcal{I}^+$, we point out some limitations, inconsistencies and anomalies that need to be addressed.

Abhishek Rajhans

Energetics of the solar atmosphere

The excess temperature of the solar corona over the photosphere poses a chal- lenge. Multiple energetic events contribute to maintaining the corona at such high temperatures. The energy released in different events can vary across several orders of magnitude. Large energy events of geomagnetic importance like flares and coronal mass ejections (CMEs) contribute little to the global energetics of the solar corona. Therefore, events with several (9-10) orders of magnitudes of lower energy, with much higher frequency of occurrence,need to be studied in great detail. Observations suggest that these impulsive events with different energies follow a power-law distribution, indicating a common underlying mechanism. We perform observation-motivated modeling of coronal loops (magnetic flux tubes) to understand the energetics of these small transient events and their similarity with impulsive events like flares. This thesis uses the EBTEL code based on the 0D hydrodynamical description of coronal loops. This approach is appropriate for getting quick estimates of the energetics of the system over a wide range of parameters. We then discuss the improvement of EBTEL to make it suitable over a broader range of parameters. This is followed by using improved EBTEL to explore the possibility of simulating impulsive events of different energy generated using a single power-law distribution. Comparison between observed emis- sions from various components of multi-thermal plasma and hydrodynamical models suggest the heating to be impulsive. Since field-aligned flows induced due to impulsive events are a crucial part of our modeling of coronal loops, we discuss the implications of such flows in the context of transition region heating.

Prakash Tripathi

Accretion Disk/Corona Emission From Active Galactic Nuclei

Active Galactic Nuclei (AGNs) are among the most powerful sources in the Universe with the bolometric luminosity ranging from $\sim 10^{41}$ to $\sim 10^{47}$ ergs s^{-1}. The origin of such enormous luminosity from an active galaxy is believed to be via accretion of matter from the host galaxy onto the central supermassive black hole (SMBH) of mass $\sim 10^5 - 10^{10} M_{\odot}$. AGNs emit photons across the entire electromagnetic spectrum from radio to X-rays and $\gamma-$rays. Despite extensive studies in the last three decades, the physical processes occurring in the central engine of AGNs, the structure of the accretion flow, geometry of the corona, causal connections between the disk and the corona emissions, etc., have not been clearly understood. This thesis focuses on the study of UV/X-ray emission from the central engine of Seyfert 1 type AGNs, as their central engines are observed directly with no or negligible obscuration by the surrounding medium. The broadband (optical/UV to X-ray) spectral energy distribution (SED) of Seyfert 1 type AGNs consists of an optical/UV continuum which is referred to as the big-blue-bump (BBB) peaking in the UV band and extending from $\sim 1\mu$ to ~ 1000Å, an X-ray power-law component with high energy cut-off at a few 100 keV, a soft X-ray excess component below ~ 2 keV, broad/narrow iron lines in the $6 - 7$ keV range, Compton reflection hump in the $\sim 10 - 50$ keV range, complex soft X-ray absorption/emission features, and numerous broad/narrow emission lines in the optical/UV bands.

The BBB component is thought to be the direct emission from the accretion flow in the form of an accretion disk. But this component has not been well tested against accretion disk models due to a number of effects such as the host galaxy contamination and the broad/narrow emission lines contributing to the optical/UV band, uncertainty in the intrinsic extinction, and unavailability of high-quality simultaneous optical/UV and X-ray data. It is believed that the BBB photons from the inner disk interact with the hot corona. The high-energy electrons in this corona then upscatter the BBB photons to the X-ray band, thus giving rise to the X-ray power-law component with a high energy cut-off. The high energy cut-offs in the X-ray power-law component observed in several AGNs strongly support the thermal Comptonization process in the hot corona. Furthermore, a correlation found between the photon-index and the flux of the X-ray power-law is interpreted in terms of the thermal Comptonization of the disk photons in the hot corona. Despite these, there are only a few direct observational evidences of seed photons for the thermal Comptonization process in the hot corona.

The X-ray power-law component, observed directly, also illuminates the accretion disk. The illuminating X-ray photons then interact with the disk matter, thus giving rise to the reflection features including the iron line and the Compton reflection hump. At least some fraction of the soft X-ray excess emission can also arise from the X-ray reflection in the innermost accretion disk. The combination of the relativistically numerous broadened emission lines and Thomson scattered photons by free electrons in the disk gives rise to a smooth continuum (i. e. soft X-ray excess component) over and above the X-ray power-law component. Alternatively, the soft X-ray excess can also arise due to warm Comptonization where the BBB photons of the disk are upscattered to the soft X-rays in a warm ($kT_e \sim 0.3 - 0.5$ keV) and optically thick ($\tau \sim 10$) corona. In this thesis, we test the warm Comptonization and the blurred reflection models to investigate the origin of the soft X-ray excess component.

We use the high-quality optical/UV, soft and hard X-ray data acquired by various space missions such as *AstroSat*, *XMM-Newton*, *Swift*, and *NuSTAR* and investigate broadband UV/X-ray spectral variability. In this thesis, we focus on (i) testing the standard disk models, and (ii) the nature of the UV/X-ray spectral variability and the causal connection between their emitting regions. We study a bright Seyfert 1.2 AGN IC 4329A and a

changing-look AGN (CL-AGN) NGC 1566. CL-AGNs show the large-amplitude variability in their optical/UV and X-ray spectra. The origin of this drastic variability is not clearly known.

The thesis begins with an introductory chapter (see Chapter 1), in which we describe the discovery of AGNs, their classification, basic unification scheme, the broadband SEDs, and summarize our current understanding of the physical processes occurring in the central engines. At the end of this chapter, we provide the motivation and objective of this thesis. In Chapter 2, we describe various space observatories, processing of the data utilized, and the analyses techniques. We describe the main work completed in this thesis in four chapters (Chapter $3-6$). We summarize our results in Chapter 7.

We explore the BBB component of a bright Seyfert 1.2 AGN IC 4329A in Chapter 3. We use the high quality $\sim$ 87 ks far UV (FUV) and $\sim$ 94 ks near UV (NUV) data acquired with the Ultra-Violet Imaging Telescope (UVIT) onboard *AstroSat*. The excellent spatial resolution ($1-1.5$ arcsec) of the UVIT has allowed us to reliably separate the AGN and the host galaxy contributions in the FUV and NUV bands. We correct the AGN flux for the Galactic and the intrinsic extinction, and then we subtract the contribution of broad and narrow emission lines from the extinction-corrected AGN flux. Thus, we derive the intrinsic AGN flux in the FUV and NUV bands. We also use the Galactic extinction corrected AGN flux in the optical band measured with *HST* (Bentz et al. 2009, *ApJ, 697, 160*). The derived intrinsic optical/UV continuum using these data shows a clear deficiency compared to that expected from the standard disk models of the accretion disk around an estimated black hole mass of $1-2\times10^8 M_{\odot}$ for both the Kerr and Schwarzschild black holes. We find the intrinsic optical/UV continuum to be fully consistent with the standard disk models, but only if the disk emits from distances larger than $80-150$ gravitational radius. Our results imply that the standard inner disk in IC 4329A is either replaced by some optically thin, hot inner flow or it is covered by an optically thick warm corona.

In Chapter 4, we investigate the UV/X-ray spectral variability of the IC 4329A using five sets of simultaneous NUV/X-ray data acquired by UVIT, SXT (Soft X-ray Telescope), and LAXPC (Large Area X-ray Proportional Counter) instruments aboard *AstroSat* over a 5-month period. We detect large-amplitude UV variability, which is unusual for a large black hole mass AGN like IC 4329A, over such a small period of $\sim$ 80 days. In fact, the fractional variability amplitude is larger in UV band than in the X-ray band by a factor of $F_{\rm var,UV}/F_{\rm var,X-ray}\sim1.2$. This shows that the observed UV variability is intrinsic to the disk and not due to the X-ray power-law illumination. The timescale of the UV variability ($\sim$ 80 days) is consistent with the thermal timescale for IC 4329A at the transition radius between the pure disk and the warm corona, which suggests that the thermal instability near this region is most likely causing the UV variability. The 0.3–20 keV spectrum in each epoch consists of a variable X-ray power-law steepening ($\Gamma\sim1.7-2$) with increasing X-ray flux, a soft X-ray excess component well described by the warm Comptonization model with an electron temperature of $kT_w\sim0.26$ keV, and a narrow iron line. The detected UV emission acts as the primary seed photons for thermal Comptonization in the hot corona, which produces the broadband X-ray power-law continuum. The X-ray spectral variability is well described by the cooling of this corona from $kT_e\sim42$ to ~32 keV with the increasing UV flux, while the optical depth remains constant at $\tau\sim2.3$.

In Chapter 5, we explore the nature of the changing-look activity in a nearby CL-AGN NGC 1566 during its 2017–2018 outburst. We triggered *AstroSat* observations of NGC 1566 twice during the declining phase of the outburst in August and October 2018. Using the *AstroSat* observations along with two *XMM-Newton* observations in November 2015 (pre-outburst) and June 2018 (peak-outburst), we found that all primary emitting components – the X-ray power-law, the soft X-ray excess and the optical/UV continuum showed extreme variability. The X-ray power-law and the optical/UV continuum first increased by factors of $\sim$ 25 and $\sim$ 30 from the pre-outburst state to the peak-outburst state, and then decreased by factors of $\sim$ 6.8 and $\sim$ 13, respectively, in $\sim$ 4 months. The soft X-ray excess component was extremely weak, almost undetectable before the outburst in 2015, which

then increased to the maximum by a factor of ~ 245, and decreased by a factor of ~ 7 in August 2018, and again became undetectable in October 2018. At the same time, the Eddington ratio (L/L_{Edd}) increased from $\sim 0.1\%$ (2015) to $\sim 5\%$ (June 2018), then decreased to $\sim 1.5\%$ (August 2018) and $\sim 0.3\%$ (October 2018). Thus, the source made a spectral transition from a strong soft X-ray excess state to a negligible soft X-ray excess state at a few percent of the Eddington rate. The observed soft X-ray excess component at the outburst peak is fully consistent with thermal Comptonization of the optical/UV photons of the disk in a warm ($kT_w \sim 0.5$ keV) and optically thick ($\tau \sim 10$) corona. The extreme variability of the soft X-ray excess component appears to be associated with the formation of the warm corona during the outburst and disappearance of this corona toward the end of the outburst over a timescale comparable to the sound-crossing time. We suggest the radiation pressure instability in the inner regions of the accretion disk in NGC 1566 is most likely responsible for the multi-wavelength spectral variability of this source.

Further, in Chapter 6 we investigate the UV/X-ray spectral variability and thermal Comptonization in the CL-AGN NGC 1566 during its 2017–2018 outburst. We use simultaneous NUV and X-ray spectral data acquired by *XMM-Newton*, *Swift*, and *NuSTAR* missions at five different epochs from June 2018 to August 2019 during the declining phase of the 2018 outburst. The broadband UV/X-ray spectral analyses of five datasets reveal that the X-ray power-law, the soft X-ray excess and the accretion disk components were extremely variable. At high-flux levels, we found that the X-ray power-law flux was correlated with the soft X-ray excess plus the disk fluxes, while at the low-flux levels when the soft X-ray excess was absent, the X-ray power-law flux was correlated with the pure disk flux. This suggest that at the 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 in the absence of the soft X-ray excess, the pure disk emission alone provided the seed photons. We found that the X-ray power-law photon-index to be weakly variable ($\Delta\Gamma_{hot} \leq 0.06$), and it was not well correlated with the X-ray power-law flux during the declining phase of the outburst. On the other hand, the electron temperature of the corona increased from ~ 22 to ~ 200 keV with the decreasing number of seed photons from June 2018 to August 2019. At the same time, the optical depth of the corona decreased from $\tau_{hot} \sim 4$ to ~ 0.7, and the scattering fraction increased from $\sim 1\%$ to $\sim 10\%$. We interpret these changes in terms of the possible geometry variations of the hot corona, such as it was growing in size and becoming hotter with the decreasing accretion rate during the declining phase of the outburst. The disk/corona geometry of NGC 1566 is evolving with a decreasing accretion rate toward a state similar to the low/hard state of black hole X-ray binaries.

Vishal Upendran

Heating and Dynamics of the Solar Atmosphere

The solar atmosphere shows anomalous variation in temperature, starting from the 5500 K photosphere to the million-degree Kelvin corona. The corona itself expands into the interstellar medium as the free streaming solar wind, which modulates and impacts the near-Earth space weather. The precise source regions of different structures in the solar wind, their formation height, and the heating of the solar atmosphere are inextricably linked and unsolved problems in astrophysics. Observations suggest correlations between Coronal holes (CHs), which are cool, intensity deficit structures in the solar corona, with structures in the solar wind. Observations also suggest the local plasma heating in the corona through power-law distributed impulsive events. In this thesis, we use narrowband photometric, spectroscopic, and disc-integrated emission of the solar atmosphere ranging from Near Ultraviolet to X-rays along with in-situ solar wind measurements to understand (i). the source regions of the solar wind, (ii). the underlying mechanism of solar coronal heating, and (iii). the differentiation in dynamics of CHs with the background QuietÂ.SunÂ.(QS) regions, which do not show any significant signature of the solar wind. We leverage machine learning and numerical modeling tools to develop solar wind forecasting codes using interpretable AI, inversion codes to infer the properties of impulsive events and to understand the differences in the thermodynamics of CHs and QS regions. We finally present a unified scenario of solar wind emergence and heating in the solar atmosphere and discuss the implications of inferences from this thesis.

FACILITIES AT IUCAA

Computing Facility

The IUCAA Computing Facility offers state of the art computing hardware and technology rich environment 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.

IUCAA HPC facility and its scientific impact

HPC serves as one of the most important backbones for modern Astronomy. It is necessary at every stage, for making observations, processing the data, connect the observations to science, making scientific predictions, designing instruments, and planning future theoretical, observational and instrumentation studies. The HPC facilities at IUCAA have been utilised for all these activities.

These facilities have led to several major research achievements across different areas in Astronomy. Over the last decade several large scale astrophysical simulations, on various topics such as astrophysical turbulence, large scale structure formation, accretion on to compact objects, AGN feedback and galaxy formation have been carried out at the IUCAA HPC, which have been published in international journals. These simulations require substantial use of HPC systems with good interconnect between compute nodes. IUCAA HPC has also been used extensively to analyse very large scale data, of the order of several TeraBytes to PetaBytes, from observational surveys. Such large data volumes also generate associated data products during the analysis, further expanding the size of data structures. An efficient high performance system with access to large scale fast storage, as set up in IUCAA, is essential for such works.

A significant fraction of these resources were used for gravitational wave (GW) data analysis. GW signals are faint and hidden in the noise. One needs to search for hundreds of thousands of modelled signals for every second of data in years worth of data, which requires enormous amount of computation power. When the same astrophysical signal is detected in two or more detectors almost at the same time, one can claim a detection. Though the LIGO-India detector is not built yet, researchers at IUCAA and many other Indian institutions are part of the international collaboration with full access to data from the other sensitive detectors in the world, namely the LIGO detectors in USA and the Virgo detector in Italy. The Sarathi cluster at IUCAA is part of the shared resources used by the International Gravitational Wave Network (IGWN) and was used by the national and international users to search for signals in the latest observation runs of these detectors which detected several mergers of compact binary stars, some of which were interesting enough to create headlines.

Present HPC facilities

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 80 compute nodes, 4 gpu nodes with 32 cores and 384 GB (on old) & 512GB RAM (on new). 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 consists of more than 2600 Physical cores. The cluster is attached to a 2 PiB parallel file system (Lustre), which is capable of delivering 15 Gbps throughput. Theoretical computing speed of the Pegasus Cluster is 150 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 (LSC), which includes many IUCAA members and Associates. The cluster is comprised of heterogeneous compute servers, it is built in three phases. The cluster consists of more than 8000 Physical cores. The theoretical peak performance of the compute node CPUs of the cluster is nearly 530 TFlops. The cluster has 2PiB PFS storage with 30Gbps write and read (1:1) throughput.

The **Vroom cluster** is used solely for the MeerKAT Absorption Line Survey (MALS). This cluster has 21 compute nodes (DELL), 2 MDS nodes, 4 GPU notes and 2 head node which delivers 25 TF computing speed and has a parallel file system (DDN) of 3.5 PiB usable capacity attached to it. The cluster is also attached to 1 PiB archival storage for archiving/serving the processed data to international community.

HPC clusters listed in Top Supercomputers in India

Sarathi Cluster Phase III, Pegasus Cluster, and Sarathi Cluster Phase II are listed at 33th, 45th and 48th rank respectively in the list of top Supercomputers in India published on January 31, 2023. The list is maintained and supported by CDAC's Terascale Supercomputing Facility (CTSF), CDAC, Bangalore. The list is available at https://topsc.cdacb.in/filterdetailstry?page=50&slug=January2023

Urgent need for upgrades

While the HPC facilities at IUCAA have been highly successful in terms of their scientific outcome and high fraction of utilisation of the resources, the facility is due for a major upgrade. Last major upgrade happened about three years ago. A substantial quantum of funding is necessary immediately to maintain the activities and to meet the increasing demands for computation.

General computing facility

The hardware and devices currently managed by the computing facility include about 350+ servers and desktops, 100+ laptops, 80+ printers and scanners, three large High-Performance Computing systems and over 8.5 PiB of storage, in addition to diverse equipment deployed for an extensive, high throughput wired and wireless campus-wide network. The number of registered Wi-Fi devices is over 900 and e-mail accounts served by the computing facility amount to nearly 600.

IUCAA provides e-mail services to its members and associates, the total number of accounts being nearly 600. IUCAA has its own registered domain name as "iucaa.in". The WAN services are provided by the National Knowledge Network over a 1 Gbps fibre connectivity, with a fall back arrangement over a 50 Mbps line from BSNL.

In the year April 2022- March 2023 emphasis was given to implementation of:

1) Expansion of the Pegasus cluster

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. In order to reduce wait time of the computational jobs, the Pegasus cluster is augmented by adding 20 compute nodes and a set of management nodes allowing better uptime for the cluster.

2) Expansion of the MALS cluster

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 observed is transferred from South Africa to IUCAA and will be processed on IUCAA cluster. The MALS cluster was extensively used and there was requirement for an additional resource. In order to reduce the wait time in the data processing, the MALS cluster is augmented by adding 9 compute nodes and 2 GPU nodes having latest GPU to enhance the computing.

3) Installation of 36 TR chiller for new data centre

IUCAA HPC, LIGO HPC services, virtual server, VDI environment are highly critical and depends on data centre cooling. We currently have four chillers configured in three (active) + one (standby) mode. Load in the data centre is increasing, and the current cooling may not be adequate after upgrading / expanding the IUCAA and LIGO compute clusters and storage. Hence, we have installed an additional chiller with 36 TR capacity to the existing chiller setup to run services hosted in the data centre smoothly.

4) Network at SITARA Lab

Setting up of state of the art IT infra, which involves high speed LAN and Wi-Fi connectivity, computer lab that facilitates research and training for various space based and astronomical projects.

5) Support for Computer-based INAT exam

Due to the pandemic situation with restricted travel, the INAT was conducted computer-based exams through M/s. MeritTrac on various centers across India. Ms. MeritTrac conducted the computer-based examination on their digital platform on which they have provided digital UI for online examination, digital calculator, stand-alone browser without internet access, examination content management, examination administration. We have provided support in the procurement of the computer-based examination software and provided required software environment to transfer essential data from MeritTrac to IUCAA.

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 the Computer Facilities Committee for consensus.
2. Framing policy documents and finalizing them in consultation with the Computer Facilities Committee members.
3. Drawing up specification of the RFP (Request For Proposal) tender document for IUCAA IT required to be purchased and oversee all 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 LIGO, MALS, SUIT, AstroSat, Big Data etc.

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

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

18. Hardware Maintenance and General System Administration of clusters in IUCAA in coordination with OEM.

19. Assisting Library department to maintain their IT infrastructure.

20. Hosted GitLab for IUCAA users and associates.

21. Architecting new hardware solutions to address operational needs.

Staff of the Computing Facility at IUCAA.

(Picture Credit: Mr. Shashank Tarphe)

IUCAA High Performance Computing clusters namely Pegasus and Sarathi.

(Picture Credit: Mr. Shashank Tarphe)

IUCAA Library

The IUCAA library provides users access to a comprehensive collection of books and journals in astronomy, astrophysics, and related areas. The library added 51 print titles, 391 eBooks of the Springer Physics and Astronomy eBooks collection for 2022, and 246 publisher-specific eBooks, namely, Annual Reviews, John Wiley and Sons, and IPC standards. The library renewed its subscription to the Grammarly Premium and Overleaf Premium software. The library renewed its subscription to 67 journals for the year 2022.

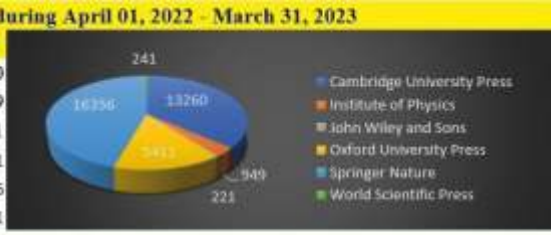
In addition to the e-journal subscriptions, the library continued to receive access to seven e-resources courtesy E-Shodh Sindhu Consortium for Higher Education Electronic Resources, MHRD, Government of India.

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

The E-Books and E-Journals usage in the year is depicted below.

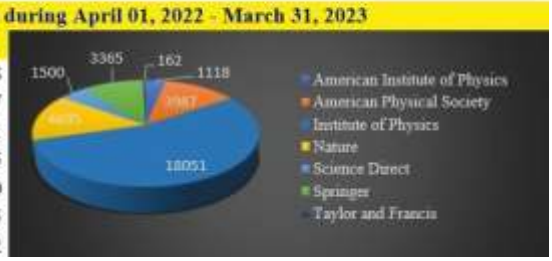
E-Books usage during April 01, 2022 - March 31, 2023

Publisher	Count
Cambridge University Press	13260
Institute of Physics	949
John Wiley and Sons	221
Oxford University Press	5411
Springer Nature	16356
World Scientific Press	241



E-Journals usage during April 01, 2022 - March 31, 2023

Publisher	Count
American Institute of Physics	1118
American Physical Society	3987
Institute of Physics	18051
Nature	4695
Science Direct	1500
Springer	3365
Taylor and Francis	162

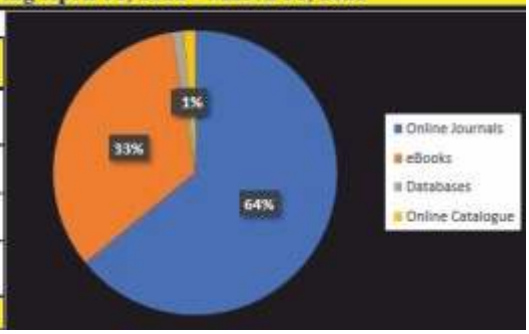


The Remotlog access and authentication software has been deployed by the library to facilitate off-campus access to all the e-resources subscribed to by the library. The following e-resources have been accessed by users including Visiting Associates of IUCAA using EZproxy.

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

Remotlog usage during April 01, 2022 - March 31, 2023

Month	Count
Online Journals	797
eBooks	414
Databases	17
Online Catalogue	16
	1244



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

1. Document Delivery Service for articles – fulfilled 218 article requests from 87 users.
2. Inter-library Loan Service: Facilitated the loan of 04 books to four libraries.
3. The library processed fifteen publication charge requests.
4. The library provided plagiarism reports using Ouriginal (formerly Urkund) for research papers.
5. The library YouTube Channel has a collection of 206 videos. With 866 new subscribers, the current subscriber base is 7433, and there have been a total of 89581 views.
6. The library staff assisted Publications Department in compiling the list of publications by IUCAA Academics and the Visiting Associates, Pedagogical Content and compilation of ICARDs, for the 2022-23 Annual Report.

ASTRONOMY CENTRE FOR EDUCATORS

Teaching Learning Centre and National Resource Centre

Refresher Course on Astronomy and Astrophysics

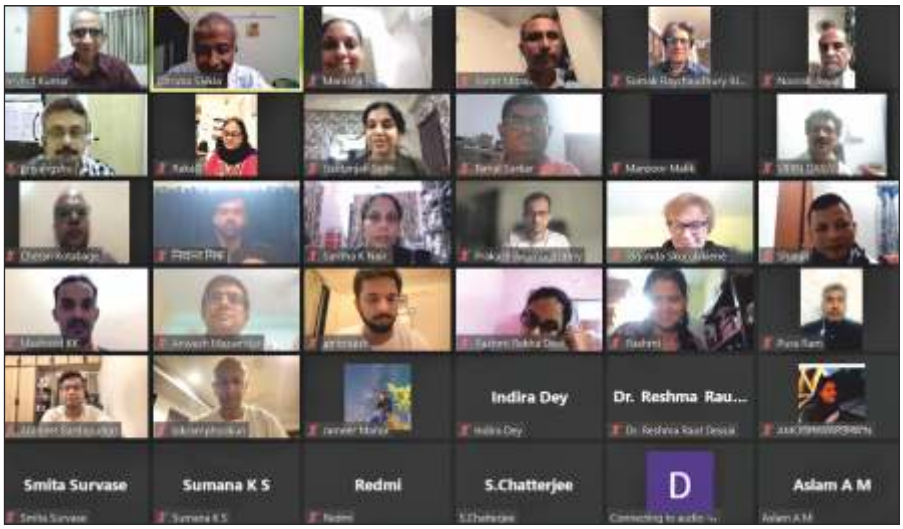
The Refresher Course on Astronomy and Astrophysics 2022 was organized online along with the IUCAA Summer School on Astronomy and Astrophysics (ISSAA) from the 16th of May to the 17th of June. The ISSAA was coordinated by Debarati Chatterjee. This was overseen by the Astronomy Centre for Educators.

Seminars on Education

The Astronomy Centre for Educators started a new seminar series titled "Seminars on Education" to discuss a wide variety of topics related to education with some emphasis on science and astronomy education. Topics will include but not limited to the conceptual aspects of the discipline, teaching-learning or pedagogic processes, philosophy and sociology of science teaching, theoretical questions related to the nature and development of science and education, core issues of access, equity, and financing of education, to name a few.

The first talk in this series was delivered by Professor Arvind Kumar, former Centre Director of the Homi Bhabha Centre for Science Education (HBCSE), a National Centre of Tata Institute of Fundamental Research, on the 30th of April. He spoke on the theme of "Reasoning and explanation in science: a pedagogical perspective". He discussed the kinds of reasoning, some of which are acceptable in modern science while others are not, with special reference to physics. The pictures show the poster and a section of the audience.

Professor Padma M. Sarangapani, Chairperson, Centre for Excellence in Teacher Education, Tata Institute of Social Sciences, Mumbai, delivered the second talk in this series titled "Ideas that matter: some key imperatives and insights that have changed the way we think about learning and teaching" on the 11th of June. She spoke on pedagogical content knowledge (PCK), the idea of the active learner and the right to education. The pictures show the poster and Professor Sarangapani delivering her talk.



Science, Astronomy and Society

The Astronomy Centre for Educators of IUCAA in collaboration with the Maharashtra State Faculty Development Academy (MSFDA) of the Government of Maharashtra is holding a series of workshops on the theme of science, astronomy and society in different towns of Maharashtra. The objectives are to expose faculty members of colleges and universities to the exciting developments in astronomy, instill motivation and fascination in them towards science in general, with emphasis on astronomy and astrophysics, and underline their importance for societal development.

The first workshop was held at the campus of the Tata Institute of Social Sciences in Tuljapur from the 2nd to the 4th of December. The resource persons were Dhruba J Saikia (IUCAA) who spoke on our multi-coloured Universe and breakthrough contributions by women in astronomy; Prakash Arumugasamy (IUCAA) who dwelt on the birth and death of stars, Jameer Manur (IUCAA) who introduced them to appreciating the night sky, and Sridhar Modugu (TISS Tuljapur) who gave them a glimpse of the history of science. In addition there were bird-watching sessions in the morning and sky-watching sessions at night which were popular not only with the participants but the TISS Tuljapur community and several who came from Solapur as well. Suhasini Desai and her team

from MSFDA along with ACE IUCAA team coordinated the programme, with active support from Ramesh Jare, Deputy Director, TISS Tuljapur and Ganesh Chadre, TISS Tuljapur. The images are from the sky-watching sessions and a group of participants after a bird-watching session

Radio Astronomy Winter School 2022

IUCAA and NCRA–TIFR jointly conducted the 15th Radio Astronomy Winter School 2022 from 13 December 2022 to 23 December 2022. Since 2019, the Teaching Learning Center of IUCAA has been organizing the school, adopting a teaching-learning model. In this model, we also invite college and university faculty members to mentor the student groups formed for the school's activities. This year, we invited five faculty members and 27 student participants out of 665 applicants.

The lecture sessions started with a broad historical overview of radio astronomy and various radio observation techniques. The later lecture sessions covered radiative processes, the Sun, pulsars, fast radio bursts, interstellar medium, galaxies, black holes, and galaxy clusters, emphasizing the role of radio observations in revealing the nature of the systems. In the afternoon and early morning sessions, the participants worked in groups with their faculty mentors on experiments characterizing detector noise, gain, and directionality. They also used a horn antenna to observe the 21-cm Hydrogen emission to obtain Galaxy rotation curves. A highlight of the school was a day trip to the Giant Metrewave Radio Telescope, where the participants got a guided tour of the observatory's design and functioning by Subhashis Roy and Avinash Deshpande. On the final day, the student groups presented one of their chosen experiments and competed in a game-style quiz on the topics taught in the school. The

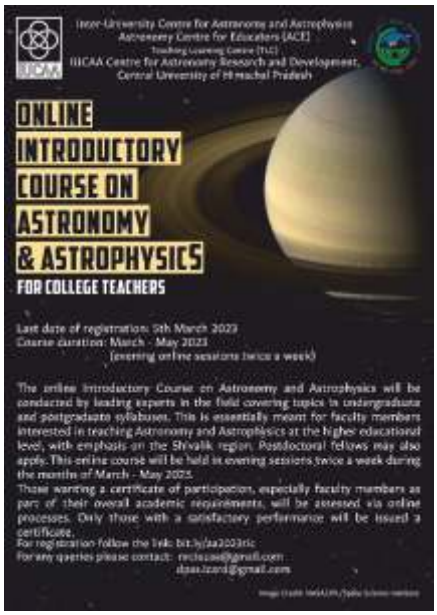
students and faculty's enthusiasm and active participation helped make this an enjoyable educational event. The organizing committee comprised Ashish Mhaske, Avinash Deshpande, Dhruba J Saikia, Jameer Manur, and Prakash Arumugasay from IUCAA and Subhashis Roy from NCRA-TIFR. The lecture recordings from the school after reviewing and editing are available through the NRC IUCAA YouTube channel.

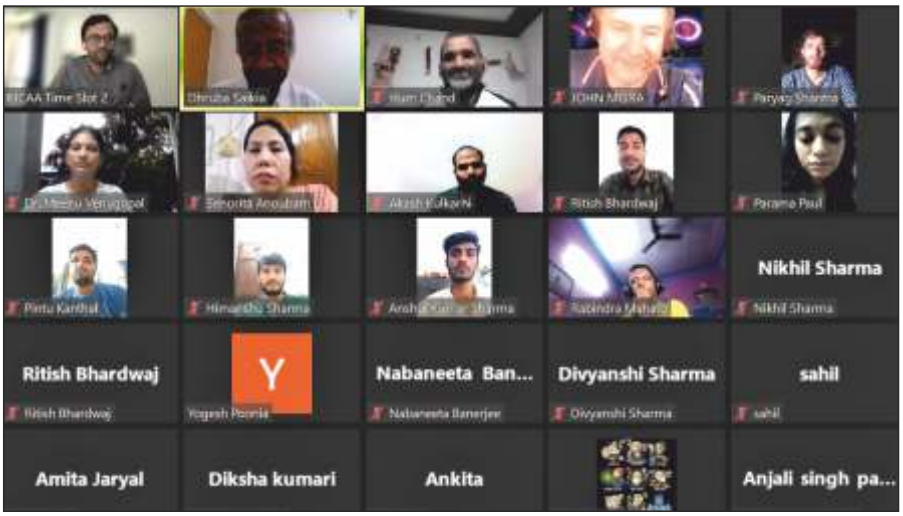
Science, Astronomy and Society

The second workshop on this theme in collaboration with the Maharashtra State Faculty Development Academy (MSFDA) of the Government of Maharashtra was held at the Walchand College of Arts and Science, Solapur on 10th and 11th of January 2023. The resource persons were Jameer Manur (IUCAA) who introduced them to appreciating the night sky, Pushpa Khare (Utkal University retired) who spoke about exploring the Universe, Prakash Arumugasamy (IUCAA) who enlightened them on the exciting area of exoplanets, Chaitanya Mungi (IISER Pune) who gave them a glimpse of astrobiology exploring the chemical origins of life, and Dhruba J Saikia (IUCAA) who spoke on the importance of building inclusive societies, taking examples from the history of astronomy. In addition there were sky-watching and bird-watching sessions, the latter being led by R. V. Hippargi, Vice-Principal of Walchand College who also gave a talk on avian ecology and diversity from endangered semi-arid grassland ecosystem. Apurve Barve and Harshada Babrekar from MSFDA and Pandurang Barkale from RUSA Mumbai coordinated the event along with ACE IUCAA Team, actively supported by Santosh Koti, Principal, Walchand College, Archana Injal and her team from Walchand College.

Introductory Course on Astronomy and Astrophysics for College Teachers

An introductory course on astronomy and astrophysics for college teachers in collaboration with the IUCAA Centre for Astronomy Research and Development at the Central University of Himachal Pradesh





started on the 22nd of March. The resource persons are Sarita Vig (IIST Trivandrum), Dhruba J Saikia and Prakash Arumugasamy (both from IUCAA), Hum Chand (Central University of Himachal Pradesh), and Jasjeet S Bagla (IISER Mohali) covering different aspects of astronomy and astrophysics. The emphasis is on faculty members from the Shivalik region to enable them to learn and teach astronomy and astrophysics as an elective paper. The course is being coordinated by Hum Chand along with the ACE IUCAA Team.

SPONSORED MEETINGS AND EVENTS OUTSIDE OF IUCAA

National Seminar on General Relativity

A National Seminar on General Relativity and Astronomy was organized by the IUCAA Centre of Astronomy Research and Development (ICARD), North Bengal University, Siliguri, West Bengal on 21 November 2022. The Seminar was dedicated to the memory of the late Professor Thanu Padmanabhan (Paddy). The seminar was attended by around 95 students including research scholars and faculty members.

(For details, see Khagol, No. 130, January – April 2023)

Advances in Astrophysics and Space Science Research

The IUCAA Centre for Astronomy Research and Development (ICARD) at the Department of Physics and Electronics, CHRIST University, Bangalore organized a three-day National Seminar on '*Advances in Astrophysics and Space Science Research*' during February 13 - 15, 2023. The seminar was aimed to provide postgraduate and motivated undergraduate students the insights and knowledge on current developments in Astronomy and Astrophysics. There were over 40 participants, who attended the seminar representing the different parts of the country. The seminar covered talks on recent advances in astronomy and astrophysics by eminent scientists, contributory talks and posters by the participants, hands-on data analysis sessions, and panel discussions.

(For details, see Khagol, No. 130, January – April 2023)

North-East Meet of Astronomers (NEMA-VIII): A Report

The eighth edition of Northeast Meet of Astronomers (NEMA -VIII) was held at the Department of Physics, Manipur University during 21-23 November 2022 under the aegis of the Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune. The aim of the NEMA-VIII conference was to bring together young and highly motivated students, researchers, and college and university teachers of the North-East region, working or intending to take up research in the field of Astronomy and Astrophysics and related topics, on a single platform to simulate discussions and collaborations. NEMA has been a regular annual event of IUCAA, Pune since it was first launched at the Department of Physics, Tezpur University

(For details, see Khagol, No. 130, January – April 2023)

Workshop on Sun and Space Weather-Impacts on the terrestrial environment

An IUCAA-supported workshop was organized by the Department of Physics, University College, Trivandrum on 15 - 16 March 2023. The workshop intended to impart basic understandings in the field of Solar-terrestrial physics to the Postgraduate and graduate students of Physics. Of the 245 applicants, 45 were selected for the programme. 41 participants were from the state of Kerala and 4 were from other states.

The workshop was inaugurated by Professor Durgesh Tripathi, IUCAA. Dr. Saji Stephen. D., Principal, University College, Trivandrum presided over the Inaugural function. Dr. Manomohan Antony, Co-ordinator, IQAC gave felicitations. Dr. Prince P.R., Assistant Professor of Physics welcomed the gathering and Dr. Madhu G., Head of the Department of Physics proposed the vote of thanks.

(For details, see Khagol, No. 130, January – April 2023)

Workshop on 'Science and Technology in Astronomy Research (STAR 2022)'

IUCAA supported a four-day international workshop on Science and Technology in Astronomy Research (STAR 2022) that was organized by Pt. Ravishankar Shukla University, Raipur from 15 to 18 October 2022. Ranjeev Misra and N.K. Chakradhari convened the workshop. There were 21 lectures by scientists and researchers. The participants got detailed information about the Universe, the development of astronomy, Giant Telescopes, Space Observatories, Supernova Explosion, the motion of celestial bodies, X-ray binaries, Black Holes, Gravitational waves, Dark Energy, Space Weather, Solar Physics, Extra-Solar Planets, Galaxies, Cosmology, and Python.

(For details, see Khagol, No. 130, January – April 2023)

Seminar on General Relativity and Gravitation

ICARD - Cooch Behar Panchanan Barma University, West Bengal organized a two-day national seminar at the university (main) campus during 22-23 November 2022. The seminar was designed to introduce the participants to General Relativity and Gravitation fundamentals and to give a flavor of recent progress in astrophysics and cosmology. The seminar was attended by more than eighty participants (post-graduate students, research scholars, and faculty members) from nearby colleges and universities.

(For details, see Khagol, No. 130, January – April 2023)

General Relativity and Cosmology

The Centre for Cosmology, Astrophysics and Space Science (CCASS), GLA University, Mathura organized a three-day workshop during 24 – 26 November 2022 on General Relativity and Cosmology (GRC-22) where esteemed Faculty / Professors from distinguished institutes were invited to speak on the thematic topics. This workshop was attended by 36 participants, PG students and PhD scholars, from all parts of India.

(For details, see Khagol, No. 130, January – April 2023)

Introductory Workshop on Astronomy and Astrophysics for Women Students

The Department of Physics, Mar Thoma College, Chungathara, in collaboration with IUCAA, Pune conducted a three-day workshop on Introductory Astronomy and Astrophysics from 06-08 December 2022. There were 42 women participants from different parts of Kerala, Tamil Nadu, and Karnataka. The sessions were handled by Prof. Annapurni Subramaniam (IIA), Prof. Indulekha K (M G University), Prof. Sarita Vig (IIST, Trivandrum), Dr. Mousumi Das (IIA), Dr. Jessy Jose (IIST, Tirupati), Dr. Sreeja S Kartha (CHRIST, Bangalore), Dr. Nayana A J (IIA), Dr. Drisya K (University of Calicut) and Dr Minu Joy (Alphonsa College, Pala, Kerala).

The workshop was coordinated by Dr. Annu Jacob (IUCAA) and Dr. Sheelu Abraham (Mar Thoma College, Chungathara).

(For details, see Khagol, No. 130, January – April 2023)

Gouri Ambika

Evidence for dynamical changes in Betelgeuse using multi-wavelength data.

The reasons behind the Great Dimming and subsequent rising in the brightness of Betelgeuse between October 2019 and March 2020 still continues to baffle astronomers. It has been shown by George et al. (2020) that critical slowing down preceded the dimming event. This suggested that the dimming was as a result of the change in the nature of the nonlinear dynamics of the star. In this work we present additional evidence for dynamical changes in Betelgeuse prior to the Great Dimming event, using nonlinear time series analysis. We study the relations between the different bands in the photometry data collected from the Wing photometry (IR/nearIR) and Wasatonic observatory (V-band). We also analyse how the early warning signals studied previously changed during and after the Great Dimming. This work has been done in collaboration with S. Kachhara. S. V.George, R. Misra.

Recurrence measures and transitions in stock market dynamics

The financial markets are understood as complex dynamical systems whose dynamics is analysed mostly using nonstationary and brief data sets from stock markets. For such data sets, the most reliable method of analysis is the one based on recurrence plots and recurrence networks, constructed from the data sets over the period of study. In this study, we do a comprehensive analysis of the complexity of the underlying dynamics of 26 markets around the globe using recurrence based measures. We also examine trends during the transitions as revealed from these measures by the sliding window analysis along the time series during the Global Financial Crisis (GFC) of 2008 and compare that with changes during the most recent pandemic related lock down. We show that the measures derived from recurrence patterns can be used to capture the nature of transitions in stock market dynamics. Thus, our study indicates that the transition in the dynamics prior to GFC is due to increasing stochasticity as seen from the recurrence measures. We also find that the markets have not stabilised after the 2020 pandemic and may possibly approach a crisis in recent future. Further the markets that go together during GFC are responding differently during the pandemic indicating that the underlying causes and mechanisms can be different. This work has been done in collaboration with Krishnadas M., K. P. Harikrishnan.

Tanwi Bandyopadhyay

Fluid Accretion upon Higher Dimensional Wormhole and Black Hole for Parameterized Deceleration Parameter

In this work, we study some parameterizations of the deceleration parameter and investi- gate the accretion of the fluid in these parameterized models upon the higher-dimensional black hole (BH) and wormholes. For the undergoing analysis, (n+2)-dimensional worm- hole (proposed by Morris and Thorne) and Schwarzschild BH were chosen in the back- drop of higher-dimensional FriedmannRobertsonWalker (FRW) space-time. For these parameterized models, we analyze the change of masses of BH and wormhole in different dimensions. This work has been done in collaboration with Ujjal Debnath.

Arunima Banerjee

Identification of Grand-design and Flocculent spirals from SDSS using deep convolutional neural network

Spiral galaxies can be classified into the Grand-designs and Flocculents based on the nature of their spiral arms. The Grand-designs exhibit almost continuous and high contrast spiral arms and are believed to be driven by stationary density waves, while the Flocculents have patchy and low-contrast spiral features and are primarily stochastic in origin. We train a deep convolutional neural network model to classify spirals into Grand-designs and Flocculents, with a testing accuracy of 97.2 percent. We then use the above model for classifying 1354 spirals from the SDSS. Out of these, 721 were identified as Flocculents, and the rest as Grand-designs. Interestingly, we find the mean asymptotic rotational velocities of our newly classified Grand-designs and Flocculents are 218 $\pm$ 86 and 146 $\pm$ 67 km s-1, respectively, indicating that the Grand-designs are mostly the high-mass and the Flocculents the intermediate-mass spirals. This is further corroborated by the observation that the mean morphological indices of the Grand-designs and Flocculents are 2.6 $\pm$ 1.8 and 4.7 $\pm$ 1.9, respectively, implying that the Flocculents primarily consist of a late-type galaxy population in contrast to the Grand-designs. Finally, an almost equal fraction of bars

0.3 in both the classes of spiral galaxies reveals that the presence of a bar component does not regulate the type of spiral arm hosted by a galaxy. Our results may have important implications for formation and evolution of spiral arms in galaxies. This work has been done in collaboration with Sarkar Suman, Narayanan Ganesh, Prakash Prem.

Indrani Banerjee

*Hunting extra dimensions in the shadow of Sgr A**

We show that the observed angular diameter of the shadow of the ultra compact object Sgr A*, favours the existence of an extra spatial dimension. This holds irrespective of the nature of the ultra compact object, i.e., whether it is a wormhole or, a black hole mimicker, but with the common feature that both of them have an extra dimensional origin. This result holds true for the mass and the distance measurements of Sgr A* using both Keck and the Gravity collaborations and whether we use the observed image or, the observed shadow diameter. In particular, the central value of the observed shadow or, the observed image diameter predicts non-zero hairs inherited from the extra dimensions. This work has been done in collaboration with Sumanta Chakraborty and Soumitra Sen Gupta.

Testing black holes in non-linear electrodynamics from the observed quasi-periodic oscillations

Quasi-periodic oscillations (QPOs), in particular, the ones with high frequencies, often observed in the power spectrum of black holes, are useful in understanding the nature of strong grhwo tavity since they are associated with the motion of matter in the vicinity of the black hole horizon. Interestingly, these high frequency QPOs (HFQPOs) are observed in commensurable pairs, the most common ratio being 3:2. Several theoretical models are proposed in the literature which explain the HFQPOs in terms of the orbital and epicyclic frequencies of matter rotating around the central object. Since these frequencies are sensitive to the background spacetime, the observed HFQPOs can potentially extract useful information regarding the nature of the same. In this work, we investigate the role of regular black holes with a Minkowski core, which arise in gravity coupled to non-linear electrodynamics, in explaining the HFQPOs. Regular black holes are particularly interesting as they provide a possible resolution to the singularity problem in general relativity. We compare the model dependent QPO frequencies with the available observations of the quasi-periodic oscillations from black hole sources and perform a χ^2 analysis. Our study reveals that most QPO models favor small but non-trivial values of the non-linear electrodynamics charge parameter. In particular, black holes with large values of non-linear electrodynamics charge parameter are generically disfavored by present observations related to QPOs.

Aru Beri

AstroSat and NuSTAR observations of XTE J1739-285 during the 2019-2020 outburst

We report results from a study of XTE J1739-285, a transient neutron star low mass X-ray binary observed with AstroSat and NuSTAR during its 2019-2020 outburst. We detected accretion-powered X-ray pulsations at 386 Hz during very short intervals (0.5-1 s) of X-ray flares. These flares were observed during the 2019 observation of XTE J1739-285. During this observation, we also observed a correlation between intensity and hardness ratios, suggesting an increase in hardness with the increase in intensity. Moreover, a thermonuclear X-ray burst detected in our AstroSat observation during the 2020 outburst revealed the presence of coherent burst oscillations at 383 Hz during its decay phase. The frequency drift of 3 Hz during X-ray burst can be explained with r modes. Thus, making XTE J1739-285 belong to a subset of NS-LMXBs which exhibit both nuclear- and accretion-powered pulsations. The power density spectrum created using the AstroSat-LAXPC observations in 2020 showed the presence of a quasi-periodic oscillation at $\sim$ 0.83 Hz. Our X-ray spectroscopy revealed significant changes in the spectra during the 2019 and 2020 outburst. We found a broad iron line emission feature in the X-ray spectrum during the 2020 observation, while this feature was relatively narrow and has a lower equivalent width in 2019, when the source was accreting at higher rates than 2020. This work has been done in collaboration with Rahul Sharma, Diego Altamirano, Nils Andersson, Fabian Gittins, and T. Celora along with my students.

The AstroSat observation of accreting millisecond X-ray pulsar SAX J1808.4-3658 during its 2019 outburst

This work has been done in collaboration with Pinaki Roy and Aditya S. Mondal. We report on the analysis of the AstroSat dataset of the accreting millisecond X-ray pulsar SAX J1808.4-3658, obtained during its

2019 outburst. We found coherent pulsations at $\sim$ 401 Hz and an orbital solution consistent with previous studies. The 3-20 keV pulse profile can be well fitted with three harmonically related sinusoidal components with background-corrected fractional amplitude of 3.5%, 1.2% and 0.37% for fundamental, second and third harmonic, respectively. Our energy-resolved pulse profile evolution study indicate a strong energy dependence. We also observed a soft lag in fundamental and hard lag during its harmonic. The broadband spectrum of SAX J1808.4-3658 can be well described with a combination of thermal emission component with kT$\sim$1 keV, a thermal Comptonization ($\Gamma\sim$ 1.67) from the hot corona and broad emission lines due to Fe. This work has been done in collaboration with Rahul Sharma and Andrea Sanna.

Piyali Bhar

Compact star in $f(T)$ gravity with Tolman-Kuchowicz metric potential

Employing $f(T)$ gravity, where T is the torson, we have developed a new model of an anisotropic compact star in this work. Tolman-Kuchowicz (TK) metric potential has been used to solve the set of field equations. Furthermore, the matching conditions for interior and exterior geometry have been discussed. We have considered observation data of the compact star LMC X-4 and analyzed thermodynamical properties (density, pressure, equation of state parameter, square speed of sound, and equilibrium condition) analytically and graphically to test the validity of the solution. The compact star is found to meet the energy conditions. Through the causality condition and Herrera's cracking concept, the stability analysis of the present model has been presented and it confirms the physical acceptability of the solution. It has been shown that the obtained interior solutions for compact stars are consistent with all necessary physical criterions and therefore relevant as well as physically acceptable.

Tolman IV fluid sphere in $f(R, T)$ gravity

In this article, we studied the behavior of relativistic spherical objects considering Tolman IV spacetime in modified $f(R, T)$ gravity for the uncharged perfect fluid matter. We have chosen the matter Lagrangian as $\mathcal{L}_m = -p$ to develop our present model. In particular, for this investigation we have reported for the compact object LMC $X-4$ [Mass=$(1.04 \pm 0.09)M_{\odot}$; Radius= $8.301^{+0.2}_{-0.2}$ Km] in our paper. The effect of the coupling parameter β on the local matter distribution of compact stars has been investigated in this paper. It can be seen that with greater values of β, the sound speed and adiabatic index are higher. On contrary, the mass function takes lower value for higher values of β. Our obtained solution does not admit singularities in the matter density, pressure and metric functions. According to our graphical analysis, this new stellar model satisfies all physical requirements anticipated in a realistic star. This work has been done in collaboration with Pramit Rej, and M. Zubair.

Priya Bharali

The study of thermonuclear X-ray bursts in accreting millisecond pulsar MAXI J1816195 with NuSTAR and NICER

The millisecond pulsar MAXI J1816-195 was recently discovered in an outburst by the Monitor of All-sky X-ray Image (MAXI) in 2022 May. We study different properties of the pulsar using data from the Nuclear Spectroscopic Telescope Array *(NuSTAR)* and the Neutron Star Interior Composition Explorer *(NICER)* observations. The unstable burning of accreted material on the surface of neutron stars induces thermonuclear (Type-I) bursts. Several such thermonuclear bursts have been detected by MAXI J1816-195 during its outburst. We investigate the evolution of the burst profiles with flux and energy using *NuSTAR* and *NICER* observations. During the *NuSTAR* observation, a total of four bursts were detected from the source. The duration of each burst is around $\sim$ 30 s and the ratio of peak to persistent count rate is $\sim$ 26 as seen from the NuSTAR data. The burst profiles are modelled using a sharp linear rise and exponential decay function to determine the burst timing parameters. The burst profiles show a relatively long tail at lower energies. The broad-band time-resolved spectra during the burst periods are successfully modelled with a combination of an absorbed blackbody along with a non-thermal component to account for the persistent emission. From our modelling results, we are able to estimate the maximum apparent emitting area of the blackbody of the neutron star to be $\sim$ 12.5 km during the peak of the outburst and the maximum distance to the object to be 8.7 kpc. Our findings for the mass accretion rate and the α factor indicate the stable burning of hydrogen via a hot CNO cycle during the bursts. This work has been done in collaboration with Manoj Mandal, Sabyasachi Pal, Jaiverdhan Chauhan, and Anne Lohfink.

Detection of X-ray reflection in MAXI J1816-195 with the NuSTAR

On 2022 June 7, an uncatalogued X-ray transient was detected by MAXI, and its location was determined by Swift. NICER has detected 528 Hz pulsations and a thermonuclear burst, leading to the source being classified as an accretion-powered millisecond pulsar. Further, NICER also measured the binary orbital period of the source to be 17402.27 s. MAXI J1816-195 was not detected in the radio frequency band (6.86 and 8.45 GHz) with the Yamaguchi Interferometer . The source has not been detected in the optical and NIR band but a probable IR counterpart was reported. NuSTAR observed MAXI J1816-195 on 2022 June 23 beginning at 10 : 31 : 52.000 (UTC) for a total exposure time of 40 ks. The source was detected at the location of RA ($J2000$) = $18h16m52.1256s$, Dec (J2000) = $19d37m58.727s$. The average background- subtracted NuSTAR count rate was 97 ± 2 cts/s (both detectors combined). We detected the 528 Hz pulsation in the *NuSTAR* data and we also observed two thermonuclear bursts, where the maximum count rate of the bursts was $\sim$ 2656 cts/s (background-subtracted). A preliminary spectral analysis revealed a spectrum describable by a disk blackbody and cut- off power-law with X-ray reflection features. We include low-energy *Swift/XRT* data, and model our initial spectra with the blackbody accretion disk model and the self-consistent ionized rreflection model. We found an absorption column of $NH = 2.65 \pm 0.13 \times 10^{22} cm^{-2}$, a disk temperature of 0.49 ± 0.03 keV, a photon index of 1.76 ± 0.07, and a high energy cut-off of 32 ± 4 keV. We calculated the unabsorbed total X-ray flux and disk flux to be $\sim 3.5e^{-9}$ $erg/s/cm^2$ and $\sim$ $5.3e^{-10}$ $erg/s/cm^2$, respectively, in the energy band $0.5-65.0$ keV. For our initial fitting the reduced $chi2/dof = 1.06/1714$. We thank the *NuSTAR* SOC Team for making these observations possible. This work has been done in collaboration with Jaiverdhan Chauhan, Manoj Mandal, Paul Draghis, et al.

Srijit Bhattacharjee

A study of black hole horizons with (semi) analytic approaches

We attempt to address the question of whether standard tests of general relativity can detect the presence of a black hole carrying a supertranslation field. In this regard, we study the photon sphere of a dynamical black hole carrying a supertranslation hair. We find that the dynamics of the photon sphere is quite subtle and it may offer an opportunity to differentiate a supertranslated black hole from its bald counterpart. This represents a first step toward understanding the observational signatures of a supertranslated dynamical black hole. This work has been done in collaboration with Subhodeep Sarkar, and Shailesh Kumar.

Debbijoy Bhattacharya

Multiwavelength study of radio galaxy Pictor A: detection of western hotspot in far-UV and possible origin of high energy emissions

A comprehensive study of the nucleus and western hotspot of Pictor A is carried out using AstroSat observations, 13 yr of Fermi, and archival Swift observations along with other published data. We report the first detection of the western hotspot of Pictor A in the far-UV band using observations from AstroSat-UVIT. The broad-band SED of the western hotspot is explained by a multizone emission scenario, where X-ray emission is caused by synchrotron emission process in the substructures embedded in the diffuse region, while the emission in radio to optical is caused by synchrotron emission process in the diffuse region. We do not notice any excess in the IR band and an additional zone (beyond 2-zone) is not required to account for the X-ray emission. Our broad-band spectro-temporal study and associated modelling of the core and hotspot of Pictor A suggests that (a) γ-rays originate in the nuclear jet and not from the hotspot (b) X-ray emission from the core of Pictor A has nuclear jet-origin instead of previously reported disc-origin. This work has been done in collaboration with Sanna Gulati.

Long-Term Monitoring of Blazar PKS 0208-512: A Change of γ-Ray Baseline Activity from EGRET to Fermi Era

The blazar PKS 0208-512 was in the lowest γ-ray brightness state during the initial 10 years of observations with the Fermi Gamma-ray Space Telescope (Fermi), which was an order of magnitude lower than its flux state during the EGRET era (1991-2000). The weekly averaged maximum γ-ray flux of this source during the first 10 years of Fermi observation is nearly a factor of 3 lower than the highest flux observed by EGRET in a single epoch. During the period 2018-2020, the source showed a large γ-ray flare, with the average brightness similar to the period 1991-2000. We observed the source with AstroSat,

during its low and high activity states, respectively. We carried out broad-band spectral energy distribution (SED) modeling of the source using a one-zone leptonic emission model during its various brightness states. From the SED modeling, we found that there was an inefficient conversion from the bulk energy to the particle energy during the long-term low-activity states as compared to the high flux state during the EGRET era and the later part of Fermi observation. This work has been done in collaboration with Krishna Mohana A.

Naseer I. Bhat

Very-high-energy flat spectral radio quasar candidates

The attenuation of very-high-energy (VHE) photons by the extragalactic background light (EBL) prevents the observation of high-redshift flat spectrum radio quasars (FSRQs). However, the correlation of the VHE spectral index with source redshift suggests that the EBL intensity may be less than what is predicted. This deviation can draw new constraints on the opacity of the Universe to VHE gamma-rays. Therefore, more FSRQs may fall above the sensitivity of the forthcoming VHE telescopes than the ones predicted by the existing EBL models. In order to account for the lower EBL intensity predicted by the index-redshift correlation, we introduce a redshift-dependent correction factor to the opacity, estimated from a commonly used cosmological EBL model. Considering this modified opacity, we identify the plausible VHE FSRQ candidates by linearly extrapolating the Fermi gamma-ray spectrum at 10 GeV to the VHE regime. Our study suggests that among 744 FSRQs reported in the Fermi Fourth Catalogue Data Release 2, 32 FSRQs will be detectable by the Cherenkov Telescope Array Observatory (CTAO). Because FSRQs are proven to be highly variable, we assume a scenario where the average Fermi gamma-ray flux increases by a factor of 10, and this predicts an additional 90 FSRQs that can be detected by the CTAO. This work has been done in collaboration with Zahoor Malik, Sundar Sahayanathan , Zahir shah, Aqqib Manzoor, and Nilay Bhat.

Multiwavelength study of blazar 4C + 01.02 during its long-term flaring activity in 2014-2017

We conducted a detailed long-term spectral and temporal study of flat spectrum radio quasar 4C +01.02, by using the multi-wavelength observations from *Fermi*-LAT, *Swift*-XRT, and *Swift*-UVOT. The 2-day bin γ-ray lightcurve in the 2014-2017 active state displays 14 peak structures with a maximum integral flux (E > 100 MeV) of $(2.5 \pm 0.2) \times 10^{-6}$ ph cm^{-2} s^{-1} at MJD 57579.1, which is approximately 61 times higher than the base flux of $(4.1 \pm 0.3) \times 10^{-8}$ ph cm^{-2} s^{-1}, calculated by averaging the flux points when the source was in quiescent state. The shortest γ-ray variability of 0.66 ± 0.08 days is observed for the source. The correlation study between γ-ray spectral index and flux suggests that the source deviates from the usual trend of harder when brighter feature shown by blazars. To understand the likely physical scenario responsible for the flux variation, we performed a detailed broadband spectral analysis of the source by selecting different flux states from the multi-wavelength lightcurve. A single zone leptonic model was able to reproduce the broadband spectral energy distribution (SED) of each state. The parameters of the model in each flux state are determined using a χ^2 fit. We observed that the synchrotron, synchrotron-self-Compton (SSC), and External-Compton (EC) processes produce the broadband SED under varied flux states. The adjoining contribution of the seed photons from the broad-line region (BLR) and the IR torus for the EC process are required to provide adequate fits to the GeV spectrum in all the chosen states. This work has been done in collaboration with Zahoor Malik, Sundar Sahayanathan , Zahir Shah, and Aqqib Manzoor.

Subhra Bhattacharya

Mimicking the ΛCDM Universe through inhomogeneous space-time

Starting from an inhomogeneous space-time model of the universe we could recreate a scenario of recent time accelerating universe dominated by Dark Energy type of fluid. The background matter component of such a universe was considered to be made up of a combination of an anisotropic fluid, a barotropic fluid and the presureless cold dark matter. It was found that inhomogeneity exhibits itself as the curvature term in such a universe. We corroborated our model with recent supernova Ia-JLA data together with H_0 data and BAO data. Cosmographic analysis of the dynamical variables further show that the model can mimic the ΛCDM cosmology very closely.

Revisiting Barrow's Graduated Inflationary Universe: A Warm perspective

It is presumed that thermal fluctuations present during inflationary epoch can make inflaton scalar field to

interact with other fields resulting in the existence of a thermal component during the inflationary period. The presence of this thermal component assists structure formation and reduces reheating dependence as in the contemporary inflationary paradigm. This is known as warm inflation. In 1990 J . D. Barrow (Phys. Lett. B **235** 40 (1990)) considered a scenario of inflation with matter field having a phenomenological equation of state of the type $p+\rho = \gamma\rho^{\lambda}$, $\gamma \neq 0$ and λ constant. He called such inflationary scenarios as "graduated inflation". In this work we reconsider the above equation of state in a scenario of warm inflation. Our aim would be to investigate and understand whether such matter can also act as a viable candidate for warm inflation.

Ritabrata Biswas

Dynamical System Study for Accretion Discs: Differences between Dark Energy and Adiabatic Profiles

In this article accreting scenarios for adiabatic and dark energy both are chosen to construct phase portrait analysis. Components of Navier Stokes equations and equation of state are picked to construct the nonlinear dynamics of accretion. Central singularities are observed to be formed in the phase diagram. Different regions in the phase diagrams are partitioned to study the nature of the gradients for radial speed and sonic speed. This study may show some lights on the inner disc activities. This work has been done in collaboration with Giridhari Deogharia.

Extension of Thermodynamics of the Kerr-Sen Black Hole under General Uncertainty Principle along with First-Order Corrected Entropy

A four-dimensional solution of the classical equation of motion in the low energy effective field theory for heterotic string theory is chosen. Popularly this is known as Kerr-Sen black hole. Thermodynamic picture is constructed. Under the generalized uncertainty principle, first-order correction of it in connection with the thermal heat capacity (THC) and due to conformal field theory (CFT) background are studied. All the cases are pointing toward an unstable thermodynamic phase of the concerned black holes. Phase transitions are located by studying where signs of the heat capacity are changing. Unlike the black holes embedded in AdS space, first-order corrected entropy is found to be unphysical. Photons by tunnelling rate are calculated. A comparative study of the effect of generalized uncertainty principle parameter α along with the black holes' parameters on the thermodynamics of the black hole is presented. This work has been done in collaboration with Amritendu Haldar, and Buddhadeb Ghosh.

Chandrachur Chakraborty

Primordial Black Holes having Gravitomagnetic Monopole

A primordial black hole (PBH) is thought to be made of the regular matter or ordinary mass (M) only, and hence could have already been decayed due to the Hawking radiation if its initial ordinary mass were $\lesssim 5 \times 10^{11}$ kg. Here, we study the role of gravitomagnetic monopole for the evaporation of PBHs, and propose that the lower energy PBHs (equivalent to ordinary mass $M << 5 \times 10^{11}$ kg) could still exist in our present Universe, if it has gravitomagnetic monopole. If a PBH was initially made of both regular matter and gravitomagnetic monopole, the regular matter could decay away due to the Hawking radiation. The remnant gravitomagnetic monopole might not entirely decay, which could still be found as a PBH in the form of the pseudo 'mass-energy'. If a PBH with $M \gtrsim 5 \times 10^{11}$ kg is detected, one may not be able to conclude if it has gravitomagnetic monopole. But, a plausible detection of a relatively low energy (equivalent to 2.176×10^{-8} kg $< M \lesssim 5 \times 10^{11}$ kg) PBH in future may imply the existence of a gravitomagnetic monopole PBH, which may or may not contain the ordinary mass. This work has been done in collaboration with Sudip Bhattacharyya.

Koushik Chakraborty

A study on the effect of anisotropy under Finch-Skea geometry

The popularity of the Finch-Skea ansatz to describe a relativistic stellar model has encouraged us to study the analytic solutions of the Einstein field equation. We have presented a class of exact solutions to the field equations after considering the corresponding two cases: (i) positive value of an anisotropic parameter, and (ii) absence of any anisotropy. Smooth matching of the interior solutions with the Schwarzschild exterior solution helped us to determine constants. The physical features of the solutions thus obtained have been studied graphically as well as numerically for specific pulsars. The stability conditions for the model have also been discussed, however, the model is found to be stable

for zero anisotropy. This work has been done in collaboration with Shyam Das, Lipi Baskey, and Saibal Ray.

Quark matter supported wormhole in third order Lovelock gravity

It is generally believed that wormholes are supported by exotic matter violating Null Energy Condition (NEC). However, various studies of wormhole geometries under Lovelock theories of gravity have reported existence of wormhole supported by matter satisfying NEC. Being inspired by these results, we explore the possibility of the existence of wormhole supported by normal quark matter in third order Lovelock gravity theory. Well known MIT Bag Model Equation of state is chosen for describing the quark matter. Taking physically acceptable approximations, we solve the field equations for shape function which satisfies flare out condition. The residual of the approximate solution is studied for accuracy and found to be acceptable. This work has been done in collaboration with Abdul Aziz, Farook Rahaman, and Saibal Ray.

Subenoy Chakraborty

The Raychaudhuri Equation in inhomogeneous FLRW space-time : A $f(R)$-gravity model

In general description of the Raychaudhuri equation it is found that this first order non-linear differential equation can be written as a second order linear differential equation in the form of Harmonic Oscillator with varying frequency. Further, the integrability of the Raychaudhuri equation has been studied and also the expansion scalar is obtained in an explicit form. Subsequently, $f(R)$ gravity theory has been studied in the background of inhomogeneous FLRW spacetime with an aim to formulate the Raychaudhuri Equation. A congruence of time-like geodesics has been investigated using the Raychaudhuri Equation to examine whether the geodesics converge or not and some possible conditions are determined to avoid singularity. Finally, a brief quantum description has been presented. This work has been done in collaboration with Madhukrishna Chakraborty and Akash Bose.

Observational constraints on f(R,T) gravity with f(R,T) = R + h(T)

The present cosmological model deals with modified $f(R,T)$ gravity theory with $f(R,T) = R + h(T)$ in the background of homogeneous and isotropic FLRW spacetime model. Four choices of $h(T)$ have been studied and examined from two observational data sets. It is found that model III, namely, the linear combination of power law and logarithmic form is more consistent with observed data than the others. However, all four considered models are a worse fit than the LCDM model. This work has been done in collaboration with Gopal Sardar, and Akash Bose.

Nand K. Chakradhari

Type Ia supernovae SN 2013bz, PSN J0910 + 5003, and ASASSN-16ex: similar to 09dc-like?

We present optical photometric and spectroscopic studies of three supernovae (SNe): SN 2013bz, PSN J0910 + 5003, and ASASSN-16ex (SN 2016ccj). UV–optical photometric data of ASASSN-16ex obtained with the *Swift* Ultraviolet/Optical Telescope (UVOT) are also analysed. These objects were initially classified as 09dc-like type Ia SNe. The decline-rate parameters ($\Delta m_{15}(B)_{true}$) are derived as 0.92 ± 0.04 (SN 2013bz), 0.70 ± 0.05 (PSN J0910+5003) and 0.73 ± 0.03 (ASASSN-16ex). The estimated B band absolute magnitudes at maximum: −19.61 ± 0.20 mag for SN 2013bz, −19.44 ± 0.20 mag for PSN J0910+5003 and −19.78 ± 0.20 mag for ASASSN-16ex indicate that all the three objects are relatively bright. The peak bolometric luminosities for these objects are derived as $\log L_{\rm bol}^{\rm max} = 43.38 \pm 0.07\,{\rm erg\,s^{-1}}$, $43.26 \pm 0.07\,{\rm erg\,s^{-1}}$ and $43.40 \pm 0.06\,{\rm erg\,s^{-1}}$, respectively. The spectral and velocity evolution of SN 2013bz is similar to that of a normal SN Ia, hence it appears to be a luminous, normal type Ia supernova. On the other hand, the light curves of PSN J0910 + 5003 and ASASSN-16ex are broad and exhibit properties similar to 09dc-like SNe Ia. Their spectroscopic evolution shows similarity with 09dc-like SNe: strong C II lines are seen in the pre-maximum spectra of these two events. Their photospheric velocity evolution is similar to SN 2006gz. Further, in the UV bands, ASASSN-16ex is very blue, like other 09dc-like SNe Ia. This is a collaborative work of Shrutika Tiwari, N. K. Chakradhari, D.K. Sahu, G. C. Anupama, Brajesh Kumar and K.R. Sahu.

Can the Violent Merger of White Dwarfs Explain the Slowest Declining Type Ia Supernova SN 2011aa?

We present optical observations and Monte Carlo radiative transfer modeling of the Type Ia supernova (SN Ia) SN 2011aa. With a $\Delta m_{15}(B)$ of 0.59 ± 0.07

mag and a peak magnitude M_B of -19.30 ± 0.27 mag, SN 2011aa has the slowest decline rate among SNe Ia. The secondary maximum in I-band is absent or equally bright as the primary maximum. The velocity of C II is lower than the velocity of Si II. This indicates either presence of C at lower velocities than Si or a line of sight effect. Application of Arnett's radiation diffusion model to the bolometric light curve indicates a massive ejecta M_{ej} $1.8 - 2.6$ $M_\odot$. The slow decline rate and large ejecta mass, with a normal peak magnitude, are well explained by double degenerate, violent merger explosion model. The synthetic spectra and light curves generated with `SEDONA` considering a violent merger density profile match the observations. This is a collaborative work of Anirban Dutta, G. C. Anupama, Nand Kumar Chakradhari and D. K. Sahu.

Hum Chand

Evidence of underdeveloped torus and broad-line region of weak emission line quasars based on their spectral energy distribution

To unravel the dominant cause of the weak emission line in a subset of optically selected radio-quiet 'weak emission line quasars' (WLQs), we have investigated the possibility of an underdeveloped broad line region (BLR). For this, we have modeled spectral energy distributions (SED) of 61 WLQs by using their optical and infrared (IR) photometric observations from SDSS and WISE respectively. SED fit consists of various emission components, including the luminosity from the dusty torus (L_{tor}). For comparison with the normal quasar, we have used a control sample of 55 QSOs for each WLQs matching in emission redshift and SDSS r-band. Based on our measurement of L_{tor}, we found a decrement of $42 \pm 2\%$ in IR-luminosity in WLQs w.r.t the control sample of normal QSOs. Using L_{tor}/L_{bol} as the measure of torus covering factor (CF_{tor}) we found a similar decrement in WLQs covering factor, with their CF_{tor} distribution being significantly different w.r.t. the normal QSOs with a KS-test P_{null} of 4.27×10^{-14}. As dusty torus and BLR covering factors are expected to be of a similar order in AGN, our results suggest that the BLR in the WLQs is underdeveloped and could be a dominant cause of the weakness of their emission line. As a result, our analysis gives support to the models of WLQs based on the evolution scenario being in an early stage of AGNs. This work has been done in collaboration with Ritish Kumar, and Ravi Joshi.

Accretion disc sizes from continuum reverberation mapping of AGN selected from the ZTF survey

We present the accretion disk size estimates for a sample of 19 active galactic nuclei (AGN) using the optical g, r, and i band light curves obtained from the Zwicky Transient Facility (ZTF) survey. All the AGN have reliable supermassive black hole (SMBH) mass estimates based on previous reverberation mapping measurements. The multi-band light curves are cross-correlated, and the reverberation lag is estimated using the Interpolated Cross-Correlation Function (ICCF) method and the Bayesian method using the JAVELIN code. As expected from the disk reprocessing arguments, the $g - r$ band lags are shorter than the $g - i$ band lags for this sample. The interband lags for all, but 5 sources, are larger than the sizes predicted from the standard Shakura Sunyaev (SS) analytical model. We fit the light curves directly using a thin disk model implemented through the JAVELIN code to get the accretion disk sizes. The disk sizes obtained using this model are on an average 3.9 times larger than the prediction based on the SS disk model. We find a weak correlation between the disk sizes and the known physical parameters, namely, the luminosity and the SMBH mass. In the near future, a large sample of AGN 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 disk. This work has been done in collaboration with Vivek Kumar Jha, Ravi Joshi,Chand, et al.

Ramesh Chandra

Extreme-Ultraviolet Wave and Accompanying Loop Oscillations

We present the observations of an extreme-ultraviolet (EUV) wave, which originated from the active region (AR) NOAA 12887 on 28 October 2021, and its impact on neighboring loops. The event was observed by the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory (SDO) satellite at various wavebands and by the Solar TErrestrial RElations Observatory-Ahead (STEREO-A) with its Extreme-Ultraviolet Imager (EUVI) and COR1 instruments with a different view angle from SDO. We show that the EUV-wave event consists of several waves as well as nonwave phenomena. The wave components include: the fast-mode part of the EUV wave event, creation of oscillations in nearby loops, and the appearance of wave trains. The nonwave

component consists of stationary fronts. We analyze selected oscillating loops and find that the periods of these oscillations range from 230 - 549 s. Further, we compute the density ratio inside and outside the loops and the magnetic-field strength. The computed density ratio and magnetic field are found to be in the ranges of 1.08 - 2.92 and 5.75 - 8.79 G, respectively. Finally, by combining SDO and STEREO-A observations, we find that the observed EUV-wave component propagates ahead of the CME leading edge. This work has been done in collaboration with P. Devi, A. K Awasthi, B. Schmieder, and R. Joshi.

Analysis of the Evolution of a Multi-Ribbon Flare and Failed Filament Eruption

How filaments form and erupt are topics about which solar researchers have wondered for more than a century and they are still open to debate. We present observations of a filament formation, its failed eruption, and the associated flare (SOL2019-05-09T05:51) that occurred in active region (AR) 12740 using data from the Solar Dynamics Observatory (SDO), the SolarTerrestrial Relations Observatory A (STEREO-A), the Interface Region Imaging Spectrograph (IRIS) and the Learmonth Solar Observatory (LSO) of the National Solar Observatory/Global Oscillation Network Group (NSO/GONG). AR 12740 was a decaying region formed by a very disperse following polarity and a strong leading spot, surrounded by a highly dynamic zone where moving magnetic features (MMFs) were seen constantly diverging from the spot. Our analysis indicates that the filament was formed by the convergence of fibrils at a location where magnetic flux cancellation was observed. Furthermore, we conclude that its destabilisation was also related to flux cancellation associated with the constant shuffling of the MMFs. A two-ribbon flare occurred associated with the filament eruption; however, because the large-scale magnetic configuration of the AR was quadrupolar, two additional flare ribbons developed far from the two main ones. We model the magnetic configuration of the AR using a force-free field approach at the AR scale size. This local model is complemented by a global potential-field source-surface one. Based on the local model, we propose a scenario in which the filament failed eruption and the flare are due to two reconnection processes, one occurring below the erupting filament, leading to the two-ribbon flare, and another one above it between the filament flux-rope con?guration and the large-scale closed loops. Our computation of the reconnected magnetic flux added to the erupting flux rope, compared to that of the large-scale field overlying it, allows us to conclude that the latter was large enough to prevent the filament eruption. A similar conjecture can be drawn from the computation of the magnetic tension derived from the global field model. This work has been done in collaboration with R. Joshi, C. H. Mandrini, B. Schmieder, et al.

Suresh Chandra

Transition $2_{12} - 3_{03}$ may help for detection of methylene in a cool cosmic object

Methylene is an important astrochemical compound. Though its laboratory spectrum was analyzed in 1982, its first unambiguous detection could be feasible after more than one decade in the hot core of Orion-KL nebula and the approximate molecular cloud of the continuum source W51M through its emission line $4_{04} - 3_{13}$. Since then waiting of its further detection has now broken as it has been detected in W51 E, W51 M, W51 N, W49 N, W43, W75 N, DR21, and S140 star forming regions, and in W3 IRS5 through the same transition $4_{04} - 3_{13}$. To find potential lines of methylene, we have performed Sobolev LVG analysis of each of the ortho and para species of methylene, considering 10 rotational levels having energy up to 324 cm^{-1}. We have found only three lines, $4_{04} - 3_{13}$, $5_{05} - 4_{14}$ and $2_{12} - 3_{03}$ of methylene, which may help for its detection in a cosmic object. The line $2_{12} - 3_{03}$ lying at the lowest energy may be more helpful in a cosmic object having low kinetic temperature. This work has been done in collaboration with Mohit K. Sharma.

Anomalous phenomena in cyclopropenylidene (c-C_3H_2) with accurate collisional rate coefficients

Collisional rate coefficients are important parameters, but their calculation is a tedious task. Accurate collisional rate coefficients for collisional transitions between pure rotational levels of cyclopropenylidene (c-C_3H_2), colliding with He atom, are now available. Strong anomalous absorption line $2_{20} - 2_{11}$ at 21.587 GHz of cyclopropenylidene is found ubiquitous in interstellar medium. It is therefore worth to analyze the line spectrum of c-C_3H_2 using accurate collisional rate coefficients. After performing Sobolev analysis of c-C_3H_2, we have found four anomalous absorption lines, $2_{2,0}$ - $2_{1,1}$, $4_{4,0}$ - $4_{3,1}$, $3_{3,0}$ - $3_{2,1}$ and $4_{3,2}$ - $5_{0,5}$. We have also found two weak MASER lines, $4_{0,4}$ - $3_{3,1}$ and $5_{1,4}$ - $4_{4,1}$, which may make the detection

of c-C_3H_2 in a cosmic object more convenient. Even for low kinetic temperature and low column density of cyclopropenylidene, the detection of $2_{2,0}$ - $2_{1,1}$ transition is possible, and it may be the reason for its detection in a large number of cosmic objects. The stability of results is tested. This work has been done in collaboration with Mohit K. Sharma.

Ayan Chatterjee

Spherical Gravitational Collapse in 4D Einstein- Gauss-Bonnet theory

In this paper, we study spherical gravitational collapse of inhomogeneous pressureless matter in $n \to$ 4d Einstein- Gauss- Bonnet gravity. The collapse leads to either a black hole or a massive naked singularity depending on time of formation of trapped surfaces. More precisely, horizon formation and its time development is controlled by relative strengths of the Gauss- Bonnet coupling (λ) and the mass function $F(r,t)$ of collapsing sphere. We find that, if there is no black hole on the initial Cauchy hypersurface and $F(r,t) < 2\sqrt{\lambda}$, the central singularity is massive and naked. When this inequality is equalised or reversed, the central singularity is always censored by spacelike/timelike spherical marginally trapped surface of topology $S^2 \times \mathbb{R}$, which eventually becomes null and coincides with the event horizon at equilibrium. These conclusions are verified for a wide class of mass profiles admitting different initial velocity conditions This work has been done in collaboration with Suresh C. Jaryal .

Gravitational Collapse in the Einstein- Gauss- Bonnet Gravity

In this paper, we study gravitational collapse in the 5-dimensional Einstein- Gauss- Bonnet (EGB) theory. We construct the spherical marginally trapped surfaces and determine their evolution when the collapsing matter admits a wide class of initial density distributions. We show that their location, and time of formation depend crucially on the initial density, and the initial velocity profile of collapsing matter, as well as on the Gauss-Bonnet (GB) coupling constant. In particular, trapped surfaces only appear when the mass contained inside the collapsing spherical shell is greater or equal to the GB coupling. Otherwise, no trapped surfaces exist and the central singularity is massive and naked. This inference is verified for pressureless dust and extended for fluids satisfying equations of state. We also make a detailed comparison of these results with those in Einstein's theory, The effect of dimensionality of spacetime on these results is discussed as well This work has been done in collaboration with Avirup Ghosh and Suresh C. Jaryal.

Ritaban Chatterjee

Moderate correlation between the accretion disk and jet power in a large sample of Fermi blazars

We present the results of studying the accretion disk vs jet power for a large fraction of all the blazars detected by the Fermi Gamma-Ray Space Telescope. The disk power is inferred from the emission line luminosities obtained from published results. As indicators of jet power, we use low frequency radio luminosity from the extended jet, maximum speed of radio knots observed in the VLBA monitoring of the pc-scale jets, kinetic energy of electrons in the jet deduced from the best-fit theoretical models of their spectral energy distribution, and γ-ray luminosity with and without beaming correction. We obtain a significant correlation in most of those cases. However, we find that the correlations are often driven by the common redshift dependence of the compared quantities. In order to remove the redshift bias and probe the intrinsic correlation between the disk and jet power, we compute the partial correlation coefficient as well as the correlation in small redshift bins and find that the intrinsic disk-jet correlation is still present but weaker. In the cases, in which the common redshift dependence does not affect the result, we find that blazars do not exhibit high jet power for low disk luminosities while there are both high and low jet power for high disk luminosities. This result indicates that a powerful disk is a necessary but not sufficient condition to produce a powerful jet. This work has been done in collaboration with Garima Rajguru.

Locating the GeV emission region in the jets of blazars from months time-scale multiwavelength outbursts

It is well known that the γ-ray emission in blazars originates in the relativistic jet pointed at the observers. However, it is not clear whether the exact location of the GeV emission is less than a parsec (pc) from the central engine, such that it may receive sufficient amount of photons from the broad-line region (BLR) or farther out at 1-100 pc range. The former assumption has been successfully used to model the spectral energy distribution of many blazars. However, simultaneous detection of TeV γ-rays along with GeV outbursts in

some cases indicate that the emission region must be outside the BLR. In addition, GeV outbursts have sometimes been observed to be simultaneous with the passing of a disturbance through the so-called 'very long baseline interferometry (VLBI) core', which is located tens of pc away from the central engine. Hence, the exact location of γ-ray emission remains ambiguous. Here we present a method that we have developed to constrain the location of the emission region. We identify simultaneous months time-scale GeV and optical outbursts in the light curves spanning over 8 yr of a sample of 11 blazars. Using theoretical jet emission models we show that the energy ratio of simultaneous optical and GeV outbursts is strongly dependent on the location of the emission region. Comparing the energy dissipation of the observed multiwavelength outbursts and that of the simulated flares in our theoretical model, we find that most of the above outbursts originate beyond the BLR at approximately a few pc from the central engine. This work has been done in collaboration with Saugata Barat,and Kaustav Mitra.

Suchetana Chatterjee

Cosmological Simulations of Galaxy Groups and Clusters-II: Studying Different Modes of Feedback through X-ray Observations

The impact of feedback from active galactic nuclei (AGNs) on the cosmological evolution of the large-scale structure is a long-studied problem. However, it is still not well understood how the feedback energy couples to the ambient medium to influence the properties of AGN host galaxies and dark matter halos. In this work we investigate different modes of AGN feedback and their effect on the surrounding medium by probing the diffuse X-ray emission from the hot gas inside galaxy groups and clusters. For this purpose, we use the cosmological hydrodynamic simulation SIMBA to theoretically calculate the X-ray emission from simulated galaxy clusters/groups with the help of the Astrophysical Plasma Emission Code. We also perform synthetic observations of these systems with the Chandra X-ray telescope using the ray-tracing simulator Model of AXAF Response to X-rays. Our results show that in addition to the radiative wind mode of feedback from the AGNs, jet and X-ray modes of feedback play significant roles in suppressing the X-ray emission from the diffuse gas in the vicinity of the black hole. Our mock observational maps suggest that the signatures of AGN feedback from high-redshift objects may not be detected with the instrumental resolution of current X-ray telescopes like Chandra, but provide promising prospects for detection of these features with potential X-ray missions such as Lynx. This work has been done in Collaboration with R. Kar Chowdhury, A. Gupta,C. Sarazin, and J.L. Dai.

Radio Dichotomy in Quasars with Hβ FWHM greater than 15,000 km s^{-1}

It has been inferred from large unbiased samples that 10-15 per cent of all quasars are radio-loud (RL). Using the quasar catalogue from the Sloan Digital Sky Survey, we show that the radio-loud fraction (RLF) for high broad line (HBL) quasars, containing $H\beta$ full width at half-maximum greater than 15 000 km s-1, is $\sim$ 57 per cent. While there is no significant difference between the RL and radio-quiet (RQ) populations in our sample in terms of their black hole mass, Eddington ratio, and covering fraction (CF), optical continuum luminosity of the RL quasars are higher. The similarity in the distribution of their CF indicates that our analysis is unbiased in terms of the viewing angle of the HBL RL and RQ quasars. Hence, we conclude that the accretion disc luminosity of the RL quasars in our HBL sample is higher, which indicates a connection between a brighter disc and a more prominent jet. By comparing them with the non-HBL H β broad emission line quasars, we find that the HBL sources have the lowest Eddington ratios in addition to having a very high RLF. That is consistent with the theories of jet formation, in which jets are launched from low Eddington ratio accreting systems. We find that the [O III] narrow emission line is stronger in the RL compared to RQ quasars in our HBL sample, which is consistent with previous findings in the literature, and may be caused by the interaction of the narrow line gas with the jet This work has been done in collaboration with A. Chakraborty, A.Bhattacharjee, M.Brotherton, and R. Chatterjee.

Surajit Chattopadhyay

Inhomogeneous Equation of State and its Consequences in a Coupled Fluid Scenario and Realization of Little Rip, Pseudo Rip, and Bounce cosmology

Motivated by the work of Frampton et al. *Phys. Lett. B* **708**, 204 (2012) and Brevik et al. *Phys. Rev. D* **84** (2011) 103508, this study, carried out with Gargee Chakraborty, reports on the reconstruction schemes for the inhomogeneous equation of state first introduced by Nojiri et al. *Phys. Rev. D* **72**

(2005) 023003, and the cosmology in the scenario of coupled fluid. We have considered the viscosity through the Eckart approach in an interacting scenario. The inhomogeneous equation of state and equation of state parameters are reconstructed for the coupled dark fluid in the viscous system for the Little Rip, Pseudo Rip, and Bounce cosmology. The reconstructed equation of state parameters of holographic Ricci dark energy of the coupled fluid in non-viscous systems is phantom for both the Little Rip and Pseudo Rip cosmology. The model holographic Ricci dark energy of the coupled fluid in the non-viscous scenario for Pseudo-Rip cosmology indicates the possibility of singularity. However, the same model for the Bounce cosmology and little rip cosmology suggests the avoidance of singularity in the far future. This work has been done in collaboration with Gargee Chakraborty.

Realisation of bounce in a modified gravity framework and information theoretic approach to the bouncing point

We have reported a study on bouncing cosmology with modified generalized Chaplygin gas(mgCG) in a bulk viscosity framework. Reconstruction schemes have been demonstrated in Einstein and modified $f(T)$ gravity framework under the purview of viscous cosmological settings. We have also taken non-viscous cases into account. We have studied the equation of state (EoS) parameter under various circumstances and judged the stability of the models through the sign of the squared speed of sound. We have observed the mgCG behaving like avoidance of big rip in the presence of bulk viscosity at the turnaround point, and in non-viscous cases, a phantom-like behaviour appears. The turnaround point equation of state parameter crosses the phantom boundary, violating NEC. The role of the mgCG's model parameters has also been investigated before and after the bounce. A Hubble flow dynamics is carried out, and, it is revealed that mgCG is capable of realizing an inflationary phase as well as an exit from inflation. An $f(T)$ gravitational paradigm has also been considered, where the mgCG density has been reconstructed in the presence of bulk viscosity. The role of the parameters associated with the bouncing scale factor, describing how fast the bounce takes place, has also been studied in this framework. Finally, the reconstructed mgCG comes out to be stable against small perturbations irrespective of the presence of bulk viscosity and modified gravity scenario. Finally, the reconstruction scheme has been asset using statistical analysis, Shannon entropy. This work has been done in collaboration with Sanghati Saha.

Bhag Chand Chauhan

Muon $(g-2)$ in the $U(1)L_\mu$ - L_τ Scotogenic Model extended with vector-like fermion

The latest results of anomalous muon magnetic moment at Fermilab show a discrepancy of 4.2 σ between the Standard Model (SM) prediction and experimental value. In this work, we revisit $U(1)L_\mu - L_\tau$ symmetry within the paradigm of scotogenic model which explains muon $(g-2)$ and neutrino mass generation, simultaneously. The mass of the new gauge boson $M_{Z_{\mu\tau}}$ generated after the spontaneous symmetry breaking of $U(1)L_\mu - L_\tau$ is constrained, solely, in light of the current neutrino oscillation data to explain muon $(g-2)$. In particular, we have obtained two regions I and II, around 150 MeV and 500 MeV, respectively, in $M_{Z_{\mu\tau}} - g_{\mu\tau}$ plane which explain the neutrino phenomenology. Region I is found to be consistent with muon neutrino trident (MNT) bound ($g_{\mu\tau} \leq 10^{-3}$) to explain muon $(g-2)$, however, region II violates it for mass range $M_{Z_{\mu\tau}} > 300$ MeV. We, then, extend the minimal gauged scotogenic model by a vector-like lepton (VLL) triplet ψ_T. The mixing of ψ_T with inert scalar doublet η leads to chirally enhanced positive contribution to muon anomalous magnetic moment independent of $Z_{\mu\tau}$ mass. Furthermore, we have also investigated the implication of the model for $0\nu\beta\beta$ decay and CP violation. The non-observation of $0\nu\beta\beta$ decay down to the sensitivity of 0.01 eV shall refute the model. The model, in general, is found to be consistent with both CP-conserving and CP-violating solutions. This work has been done in collaboration with Simran Arora, Monal Kashav, and Surender Verma.

Muon (g-2) and W-boson mass Anomaly in a Model Based on Z4 Symmetry with Vector like Fermion

The latest results of the CDF-II Collaboration show a discrepancy of 7σ with standard model expectations. There is also a 4.2σ discrepancy in the measurement of the muon magnetic moment reported by Fermilab. We study the connection between neutrino masses, dark matter, the Muon (g âˆ’ 2) experiment, and the W-boson mass anomaly within a single coherent framework based on a Z4 extension of the scotogenic model with a vector-like lepton (VLL). Neutrino masses are generated at the one-loop level. The inert doublet also provides a solution to the W-boson mass anomaly through correction in oblique parameters S, T, and U.

The coupling of the VLL triplet ψ_T to the inert doublet η provides a positive contribution to the muon anomalous magnetic moment. In the model, the VLL triplet provides a lepton portal to dark matter, η_R^0. The model predicts a lower bound $m_{ee} > 0.025$ eV at 3σ, which is well within the sensitivity reach of the $0\nu\beta\beta$ decay experiments. The model explains the muon anomalous magnetic moment Δa_μ for $1.3 < y_\psi < 2.8$ and a DM candidate mass in the range 152 GeV $< M_{\eta_R^0} <$ 195 GeV. The explanation of the W-boson mass anomaly further constrains the mass of the DM candidate, $M_{\eta_R^0}$, in the range 154 GeV $< M_{\eta_R^0} <$ 174 GeV. This work has been done in collaboration with Simran Arora, Monal Kashav, and Surender Verma.

Prasanta Kumar Das

Inflationary Cosmology in a non-minimal $f(R,T)$ gravity theory using a RT mixing term

We investigate a class of inflationary models in modified gravity theories which contain a non-minimal coupling between gravity and a scalar field ϕ as $f(R,T) = R\big(1+\alpha+\kappa^4\beta T\big)+\kappa^2\gamma T$ where $\kappa^2 = 8\pi G$ where G is Newton's constant. We consider two inflaton potentials of the form (i) $V = V_0\big(1+\ln\phi\big)$ and (ii) $V_0\frac{\lambda\phi^p}{1+\lambda\phi^p}$. For different potential parameters, we have explored the constraints on the modified gravity parameters i.e. (α, β, and γ) in the following three cases: (i) $\beta \neq 0$, $\alpha = \gamma = 0$, (ii) $\alpha = 0$, $\gamma \neq 0$, $\beta \neq 0$ and (iii) $\gamma = 0$, $\alpha \neq 0$, $\beta \neq 0$ for the above two potentials. We find that by the inclusion of RT mixing term, the scalar spectral index n_s and tensor-to-scalar ratio r are consistent with the 3σ limit of the Planck data as well as $r < 0.056$. This work has been done in collaboration with Payel Sarkar, and Ashmita.

EFT analysis of leptophilic dark matter at future electron-positron colliders in the mono-photon and mono-Z channels

We consider the possibility that dark matter (DM) only interacts with the Standard Model leptons, but not quarks at tree level, and analyze the future lepton collider prospects of such leptophilic DM in the monophoton and mono-Z (both leptonic and hadronic) channels. Adopting a model-independent effective field theory framework, we consider all possible dimension-six operators of scalar-pseudoscalar (SP), vector-axial vector (VA), and tensor-axial tensor (TAT) types for a fermionic DM and derive the collider sensitivities on the effective cutoff scale Λ as a function of the DM mass. As a concrete example, we take the beam configurations of the International Linear Collider with $\sqrt{s} = 1$ TeV and 8 ab^{-1} integrated luminosity, including the effect of beam polarization, and show that it can probe leptophilic DM at 3σ level up to Λ values of 6.6, 8.8, and 7.1 TeV for the SP-, VA- and TAT-type operators, respectively. This is largely complementary to the direct and indirect searches for leptophilic DM and can potentially provide the best-ever sensitivity in the low-mass DM regime. This work has been done in collaboration with Saumyen Kundu, Atanu Guha and P. S. Bhupal Dev.

Shyam Das

Anisotropic compact objects with Finch-Skea geometry in EGB gravity

We present a new class of relativistic anisotropic stellar models with spherically symmetric matter distribution in Einstein Gauss?Bonnet (EGB) gravity. A higher dimensional Finch?Skea geometry in the theory is taken up here to construct stellar models in hydrostatic equilibrium. The Gauss?Bonnet term is playing an important role in accommodating neutron stars. We study the physical features namely, the energy density, the radial and tangential pressures and the suitability of the models. It is found that the equation of state of such stars are non-linear which is determined for a given mass and radius of known stars. The stability of the stellar models are also explored for a wide range of values of the model parameters. This work has been done in collaboration with Bibhash Das, Sagar Dey and Bikash Chandra Paul.

Central pressure-dependent compact anisotropic stellar model and its tidal Love number

We develop an anisotropic compact stellar model by assuming a Buchdahl ansazt (Phys. Rev. 116: 1027?1034, 1959)-type metric potential and a particular radial pressure profile. We analyse the tidal behaviours of such class of compact stars by estimating their tidal Love Numbers (TLN). In particular, we find a relationship between the TLN and the central density of the configuration. This work has been done in collaboration with Bikram Keshari Parida, Ranjan Sharma and Farook Rahaman.

Sudipta Das

Quintessence or phantom: Study of scalar field dark energy models through a general parametrization of the Hubble parameter

In this work we propose a simple general parametrization scheme of the Hubble parameter for the scalar field dark energy models. In our approach it is possible to incorporate both the quintessence and phantom scalar field in a single analytical scheme and write down relevant cosmological parameters which are independent of the nature of the scalar field. A general condition for the phantom barrier crossing has also been obtained. To test this approach, a well behaved parametrization of the normalized Hubble parameter has been considered and a wide variety of observational data like CMB data, Supernovae data, BAO data etc. has been used to constraint the various cosmological parameters. It has been found that data prefer the present value of the equation of state of the dark energy to be in the phantom domain. One interesting outcome of this analysis is that although the current value of the dark energy equation of state is phantom in nature, a phantom crossing of the EOS has taken place in the recent past. We have also carried out the Bayesian model comparison between ΛCDM model and the proposed model which indicates that this model is favored by data as compared to ΛCDM model. This work has been done in collaboration with Nandan Roy, Sangita Goswami.

Kanan Kumar Datta

Impact of cosmic rays on the global 21-cm signal during cosmic dawn

It is extremely important to understand the processes through which the thermal state of the inter-galactic medium (IGM) evolved in the early universe in order to study the evolution of HI 21-cm signal during cosmic dawn. Here, we consider the heating of the IGM due to cosmic ray (CR) protons generated by the supernovae from both early Pop III and Pop II stars. The low energy CR (cr protons from Pop III supernovae can escape from minihalos and heat the IGM via collision and ionization of hydrogen. Furthermore, high-energy protons generated in Pop II supernovae can escape the hosting halos and heat the IGM via magnetosonic Alfvén waves. We show that the heating due to these CR particles can significantly impact the IGM temperature and hence the global 21-cm signal at $z \sim 14 - 18$. The depth, location, and duration of the 21-cm absorption profile are highly dependent on the efficiencies of CR heating. In particular, the Experiment to Detect the Epoch of Reionization Signature signal can be well fitted by the CR heating along with the Lyman-? coupling and the dark matter–baryon interaction that we consider to achieve a 'colder IGM background'. Further, we argue that the properties of CRs and the nature of first generation of stars could be constrained by accurately measuring the global 21-cm absorption signal during the cosmic dawn. This work has been done in collaboration with Ankita Bera, and Saumyadip Samui.

Probing the Epoch of Reionization using synergies of line intensity mapping

The Epoch of Reionization (EoR) remains a poorly understood cosmic era for the most part. Yet, efforts are still going on to probe and understand this epoch. We present a review of the latest developments in the techniques (especially line-intensity mapping) to study the EoR and try to highlight the contribution of the Indian community in this field. Line-emissions like HI-21cm, Lyman- α, C II ? 158 micro meter and their role as tracers in probing the EoR are discussed. While the H I- 21cm is an excellent probe of the early IGM, the others are mainly targeted to do an unresolved and large-scale survey of the reionizing sources. Techniques to model these signals include simulations and machine learning approaches, along with the challenge to tackle foregrounds or interlopers. We also discuss synergy opportunities among the various tracers that we mention. Synergy addresses different aspects of the problem, which otherwise is difficult or impossible to tackle. They include statistics like cross-power spectrum, cross-bispectrum, and other techniques such as follow-up studies. We present updates on the relevant experiments; these include the upper limits on the H I 21cm power spectrum, along with some highlights on high-redshift galaxy surveys. Finally, we highlight what can be improved further within the community: applying machine learning and simulations based on hydrodynamic and radiative-transfer techniques. Next-generation experiments also need to be conceived to address issues currently beyond our reach. This work has been done in collaboration with Shekhar Murmu, Chandra , Raghunath Ghara; Suman Majumdar.

Partha Sarathi Debnath

Hybrid expansion law in viscous braneworld gravity with Gauss Bonnet terms

The cosmological model executing hybrid expansion law of scale factor in Randall-Sundrum type II (RS) braneworld gravity with Gauss Bonnet terms in the presence of bulk viscosity described by Eckart theory, Truncated Israel Stewart (TIS) theory, Full Israel Stewart (FIS) theory and nonlinear Israel Stewart (nIS) theory are studied. In the hybrid expansion law (HEL) the scale factor of the universe is described by the product of power-law and exponential expansions. In the HEL model the early inflation and its transition from deceleration phase to present accelerated phase of expansion can be explored. The constraints of hybrid expansion law model parameters are determined using the recent observational data. Thereafter, the estimated parameters are considered to explore the present value of deceleration parameter, jerk parameter and transition epoch from early deceleration to the present accelerating phase. This work has been done in collaboration with Bikash Roy and Bikash C. Paul.

Ujjal Debnath

The General Class of Accelerating, Rotating and Charged Plebanski-Demianski Black Holes as Heat Engine

We first review the general class of accelerating, rotating and charged Plebanski-Demianski (PD) black holes in the presence of cosmological constant, which includes the Kerr-Newman rotating black hole and the Taub-NUT spacetime. We assume that the thermodynamical pressure may be described by the negative cosmological constant, and so the black hole represents anti-de Sitter (AdS) PD black hole. The thermodynamic quantities like surface area, entropy, volume, temperature, Gibb's and Helmholtz's free energies of the AdS PD black hole are obtained due to the thermodynamic system. Next, we find the critical point and corresponding critical pressure, critical temperature and critical volume for the AdS PD black hole. Due to the study of specific heat capacity, we obtain the specific heat capacity (with constant volume) $\mathcal{C}_V = 0$ and the specific heat capacity (with constant pressure) $\mathcal{C}_P \geq 0$. From this result, we conclude that the AdS PD black hole may be stable. We examine the Joule-Thomson expansion of the PD black hole, and by evaluating the sign of the Joule-Thomson coefficient μ, we determine the heating and cooling nature of the PD black hole. Putting $\mu = 0$, we find the inversion temperature. Next, we study the heat engine for the AdS PD black hole. In the Carnot cycle, we obtain the work done and its maximum efficiency. Also, we describe the work done and its efficiency for a new engine. Finally, we analyze the efficiency of the Rankine cycle in the PD black hole heat engine.

Constructions of Entropy and Modified Friedmann Equations in Gravity Theories

The FRW universe is considered a thermodynamical system. We assume that the universe filled in a perfect fluid. So we obtain apparent horizon radius, surface gravity, and temperature. Using unified first law as well as the first law of thermodynamics and Friedmann equations, we obtain the entropy-area relation on the apparent horizon in Einstein's gravity. In Horava-Lifshitz gravity, scalar-tensor gravity, $f(R)$ gravity and $f(T)$ gravity theories, using corresponding Friedmann equations, we obtain the corresponding entropies in integration forms. Next, for a power law, future singularity and de Sitter expansions, we obtain the general entropy function $F(A)$ in terms of horizon area A on different IR cutoffs like Hubble, apparent, particle, event, (m, n) type event, conformal age and Ricci horizons. Moreover, by considering general entropy, we determine the modified Friedmann equations for Horava-Lifshitz gravity, scalar-tensor gravity, $f(R)$ gravity and $f(T)$ gravity theories.

Shantanu Desai

The Indian Pulsar Timing Array: First data release

We present the pulse arrival times and high-precision dispersion measure estimates for 14 millisecond pulsars observed simultaneously in the 300-500 MHz and 1260-1460 MHz frequency bands using the upgraded Giant Metrewave Radio Telescope (uGMRT). The data spans over a baseline of 3.5 years (2018-2021), and is the first official data release made available by the Indian Pulsar Timing Array collaboration. This data release presents a unique opportunity for investigating the interstellar medium effects at low radio frequencies and their impact on the timing precision of pulsar timing array experiments. In addition to the dispersion measure time series and pulse arrival times obtained using both narrowband and wideband timing techniques, we also present the dispersion measure structure function analysis for selected pulsars.

Our ongoing investigations regarding the frequency dependence of dispersion measures have been discussed. Based on the preliminary analysis for five millisecond pulsars, we do not find any conclusive evidence of chromaticity in dispersion measures. Data from regular simultaneous two-frequency observations are presented for the first time in this work. This distinctive feature leads us to the highest precision dispersion measure estimates obtained so far for a subset of our sample. Simultaneous multi-band uGMRT observations in Band 3 and Band 5 are crucial for high-precision dispersion measure estimation and for the prospect of expanding the overall frequency coverage upon the combination of data from the various Pulsar Timing Array consortia in the near future. Parts of the data presented in this work are expected to be incorporated into the upcoming third data release of the International Pulsar Timing Array. This work has been done in collaboration with Pratik Tarafdar, Nobleson K., Prerna Rana, Jaikhomba Singha, and M. A. Krishnakumar et al.

Combined significance of spatial coincidence of high energy neutrinos from PSR B1509-58 by Super-Kamiokande and MACRO

In their searches for astrophysical point sources of high energy neutrinos, both the Super-Kamiokande and MACRO neutrino detectors saw the largest angular excess from the same source, viz. PSR B1509-58. We estimate the probability for the observed number of events by *both* Super-Kamiokande and MACRO to be a chance coincidence due to atmospheric neutrino background. We find that this probability is about 0.4%, corresponding to 2.6σ significance. We also propose some additional tests to ascertain if this excess corresponds to an astrophysical signal or is only a background event.

Shanti Priya Devarapalli

Probing TYC 3315-1807-1, An sdB+ dM Binary Displaying Strong Period Variation and Reflection Effect

Subdwarf (sdB) stars include core helium-burning stars with a very thin hydrogen envelope that lies at the blue end of the horizontal branch (or extreme horizontal branch). Among them, short-period sdB binaries especially with cool companions are significant to test and constrain binary evolution. We discuss one such sdB+dM type binary, TYC 3315-1807-1 (V1), which was first reported by Kawka. Results of the photometric analysis on Transiting Exoplanet Survey Satellite data are being reported. Light variation in the light curve suggests that the system displays a large reflection effect with no eclipses. Spectroscopic observations of the object were also carried out to probe into the nature of secondary companion as well as to understand the post-common-envelope evolution of such objects. The variability in Balmer, He, and Na line profiles as a function of phase, probably caused by observed reflection effect was identified and studied. Period variation study of the object was done using times of minima obtained from the literature and the O-C plot was produced, which points to a decrease in the period (dp/dt = -1.36315×$10^{-7} dayyr^{-1}$), and the possible scenario of evolution is discussed. From the evolutionary models, we constrain the possible mass of the sdB to be 0.274 Msun and that of the secondary is 0.113 Msun, and we conclude that V1 may evolve directly as a helium-core white dwarf. This work has been done in collaboration with Rukmini Jagirdar, Vinay Kumar Gundeboina, Vineet S. Thomas, and Srinivasa Rao Mynampati.

The First Photometric and Spectroscopic Study of Contact Binary V2840 Cygni

The first photometric, spectroscopic and period variation studies of neglected short-period eclipsing binary V2840 Cygni are presented. High mass ratio contact binaries (HMRCBs), especially those in the weak-contact configuration, are vital when probing the evolutionary models of contact binaries (CBs) using stellar parameters. The photometric solutions reveal the weak-contact nature of V2840 Cygni with a high mass ratio (1.36), motivating us to investigate the nature of such binaries. The period variation study of V2840 Cygni spanning 15 yr shows a secular period decrease at a rate of $5.5\times10^{-7} dayyr^{-1}$, indicating mass transfer between the components. The superimposed cyclic variation provides a basic understanding of the possible third body (P_3 $8yr, m_3$ $0.51Msun$). Following the derived parameters, the evolution of the system is discussed based on the thermal relaxation oscillation (TRO) model. It is found that V2840 Cygni falls in a special category of HMRCBs, which validates TRO. To characterize the nature of HMRCBs, a catalog of 59 CBs with high mass ratios has been compiled along with their derived parameters from the literature. For all the HMRCBs in the study, a possible correlation between their contact configuration and observed period variations for relative log J rel is discussed. The

spectroscopic study of V2840 Cygni provides evidence of the presence of magnetic activity in the system and the existence of ongoing mass transfer which is additionally deduced from the period variation study. The LAMOST spectra of 17 HMRCBs are collected to interpret the stellar magnetic activity in such systems. This work has been done in collaboration with Ravi Raja, and J. Rukmini.

Archana Dixit

Barrow HDE model for Statefinder diagnostic in non-flat FRW universe

Pressureless dark matter (DM) and Barrow holographic dark energy (BHDE) whose IR cutoff is the apparent horizon. Among various DE models, (BHDE) model shows the dynamical enthusiasm to discuss transition phase of the universe. According to the new research, the universe transitioned smoothly from a decelerating to an accelerating phase of expansion in the recent past. We exhibit that the development of q relies upon the type of spatial curvature. Here we study the equation of state (EoS) parameter for the BHDE model to determine the cosmological evolution for the non-flat universe. The (EoS) parameter and the deceleration parameter (DP) show the satisfactory behaviour and it does not cross the phantom line. We also plot the statefinder diagram to characterize the properties of the BHDE model by taking distinct values of the barrow exponent $\triangle$. Moreover, we likewise noticed the BHDE model in the $(\omega_D - \omega_D^{'}$ plane, which can furnish us with a valuable, powerful finding to the mathematical determination of the statefinder. In the statefinder trajectory, this model was found to be able to reach the ΛCDM fixed point. This work has been done in collaboration with V.K. Bhardwaj and Anirudh Pradhan.

Bulk Viscous Flat FLRWModel with Observational Constraints in $f(T, B)$ Gravity

This paper investigates the impact of bulk viscosity within the framework of $f(T, B)$ gravity. We consider a time-dependent viscosity model with a particular Hubble parameter expression. Here, we looked into the viability of well-motivated $f(T, B)$ gravity model, which takes the form $f = alog(B) + bT$, and has free parameters a and b. The 46 observational Hubble data (OHD) in the range $0 \leq z \leq 2.36$ were used to constrain the model parameters to achieve the solution. We have used the Markov Chain Monte Carlo (MCMC) method to estimate model parameters and observe that the model appears to be in good agreement with the observations. In addition, we evaluate the effective viscous equation of state parameter for the $f(T, B)$ model. We have examined the characteristics of different energy conditions for the stability analysis. The model is valid based on the positive behavior of null energy conditions (NEC), weak energy conditions (WEC), and dominant energy conditions (DEC); however, strong energy conditions (SEC) are in violation, suggesting that the universe is expanding faster. Our model was found in the quintom region. We also discussed how the tachyon scalar field corresponds to $f(T, B)$ gravity. This work has been done in collaboration with Anirudh Pradhan.

Broja Gopal Dutta

Time Lag Properties In Black Hole Binaries: Implication On Accretion Disk Geometry

The time lag properties of Galactic black holes are important because it gives a model independent view of accretion dynamics. The time lag properties are inclination dependent, and the explanation of time lag behavior is complex due to the non-linear physical processes contributing to the lag. The soft and hard time can be explained by considering the Comptonization, reflection, light-crossing time (i,e., an inclination of the source and focusing), and effect of outflows/Jets. We attempted various Galactic black hole transient of low (e.g., XTE J1650-500, GX 339-4 XTE J1817-330) and high (e.g., H1743-322, XTE J1550-564, GRS 1915+105) inclination and calculated time lag during the onset and declining phases of the outbursts. We find a systematic correlation of time lag with QPO frequency, and the correlation changes near 3 Hz irrespective of the inclination of these sources. These behavior indicate the implication of specified accretion geometry in producing lag. This work has been done in collaboration with S. K. Chakrabarti.

A Similar Accretion Disk Dynamics In Bare-Type Agn Ark 120 And Galactic Black Hole Binaries

We study the long-term X-ray spectral and temporal variability of a bare-type AGN Ark 120 and Galactic black hole binaries (GBHBs). We considered RXTE, XMM-Newton, Suzaku, Swift, and NuSTAR observations. We have studied the various spectral parameters such as the size of the Compton cloud, accretion rate, temperature of the electron cloud,

and optical depth using various phenomenological and physical models. We have calculated the X-ray time delay/lag between the different energy bands. The delays are explained considering Comptonization, reflection, light-crossing time, and outflows/Jets. We find that the time lag changes sign for both types of sources when accretion rate varies, and a similar variation of comptonizing region is observed from delay/lag for both types of source. We also study the correlation between the soft-excess and the primary continuum, as obtained from the long-term data in Ark 120. We conclude that the soft-excess and the primary continuum are originated from the same physical process in Ark 120, and accretion disk dynamics play an important role in producing time lag for GBHBs. This work has been done in collaboration with P. Nandi, A. Chatterjee and S. Mondal.

Jibitesh Dutta

Cosmology in f(Q) gravity: A unified dynamical systems analysis of the background and perturbations

Motivated by the fact that the non-metricity $f(Q)$ gravity could challenge the ΛCDM, in this work, we attempt to shed some light on this fact by investigating the evolution of the $f(Q)$ gravity at the background and perturbed levels using a unified dynamical system formalism. More precisely, we consider the power-law and the exponential models of $f(Q)$ gravity. From the combined analysis, we obtain saddle critical points describing the matter-dominated Universe with the desired growth of matter perturbations, allowing solutions to settle in a dark energy-dominated epoch with constant matter perturbations. Further, although the exponential model does not have ΛCDM as a limit, our analysis reveals that the model resembles the ΛCDM. Thus, the exponential model can alleviate the cosmological constant problem and be considered an alternative to the standard ΛCDM. This work has been done in collaboration with W. Khyllep, E. N. Saridakis and K. Yesmakhanova.

Mayukh Raj Gangopadhyay

Primordial black-hole dark matter via warm natural inflation

We report on a study of the natural warm inflationary paradigm (WNI). We show two important new results arise in this model. One is that the observational constraints on the primordial power spectrum from the cosmic microwave background (CMB) can be satisfied without going beyond the Planck scale of the effective field theory. The second is that WNI can inevitably provide perfect conditions for the production of primordial black holes (PBHs) in the golden window of black-hole mass range (10?16 ? 10?11MSUN) where it can account for all of the the dark matter content of the universe while satisfying observational constraints. This study has been done in collaboration with Miguel Correa, Nur Jaman, and Grant J. Mathews .

A Case Study of Small Field Inflationary Dynamics in the Einstein-Gauss Bonnet Framework in the Light of GW 170817

We study two of the most theoretically promising models of inflation, namely Natural inflation and Mutated Hilltop inflation, in the Einstein-Gauss Bonnet(EGB) gravity framework. In this work, we try to explore these models keeping observations from GW 170817 on the speed of gravitational wave to be equal to the speed of light. This has direct implications on the non-minimal coupling to the Gauss-Bonnet invariant in the action. Thus, the effective potential gets new features. We have not only analysed the inflationary dynamics, but also the reheating dynamics and finally the corresponding energy spectrum of the gravitational wave. This study has been done in collaboration with Hussain Ahmed Khan, and Yogesh.

Sudip Kumar Garain

Three-dimensional simulations of advective, sub-Keplerian accretion flow on to non-rotating black holes

We study the time evolution of sub-Keplerian transonic accretion flow onto a non-rotating black hole using a three-dimensional, inviscid hydrodynamics simulation code. Prior two-dimensional simulations show that centrifugal barrier in the accreting matter may temporarily halt the nearly free-falling matter and produce a stable, geometrically thick disk which may contain turbulent eddies. Our goal in this work is to investigate whether the disk develops any instability because of this turbulence when we dynamically activate all three dimensions. We find that the disk remains stable and axisymmetric even close to the central black hole. However, if we explicitly apply non-axisymmetric azimuthal perturbation, the axisymmetric structure of the disk is destroyed and instability is developed. This study has been done in collaboration with Kim, Jinho.

Prabir Gharami

Tidal Angular Momentum in Close Binary Systems in Presence of Wind Driven Non-conservative Mass Transfer with Uniform Mass Accretion Rate

A very well-known property of close binary stars is that they usually rotate slowly than a similar type single star.Massive stars in close binary systems are supposed to experience an exchange of mass and angular momentum via mass transfer and tidal interaction, and thus the evolution of binary stars becomes more complex than that of individual stars. In recent times, it has become clear that a large number of massive stars interact with binary companions before they die. The observation also reveals that in close pairs the rotation tends to be synchronized with the orbital motion and the companions are naturally tempted to invoke tidal friction. We here introduce the e?ect of tidal angular momentum in the model of wind driven non-conservative mass transfer taking mass accretion rate as uniform with respect to time. To model the angular momentum evolution of a low mass main sequence companion star can be a challenging task.So to make the present study more interesting, we have considered initial masses of the donor and gainer stars at the proximity of bottom line main sequence stars and they are taken with lower angular momentum. We have produced a graphical pro?le of the rate of change of tidal angular momentum and the variation of tidal angular momentum with respect to time under the present consideration. This work has been done in collaboration with Koushik Ghosh, and Farook Rahaman.

Abhik Ghosh

Towards 21-cm Intensity Mapping at $z = 2.28$ with uGMRT using the Tapered Gridded Estimator I: Foreground Avoidance

The post-reionization ($z \leq 6$) neutral hydrogen (H I) 21-cm intensity mapping signal holds the potential to probe the large scale structures, study the expansion history and constrain various cosmological parameters. Here we apply the Tapered Gridded Estimator (TGE) to estimate $P(k_\perp, k_\parallel)$ the power spectrum of the $z = 2.28$ (432.8 MHz) redshifted 21-cm signal using a 24.4 MHz sub-band drawn from uGMRT Band 3 observations of European Large-Area ISO Survey-North 1 (ELAIS-N1). The TGE allows us to taper the sky response which suppresses the foreground contribution from sources in the periphery of the telescope's field of view. We apply the TGE on the measured visibility data to estimate the multi-frequency angular power spectrum (MAPS) $C_\ell(\Delta\nu)$ from which we determine $P(k_\perp, k_\parallel)$ using maximum-likelihood which naturally overcomes the issue of missing frequency channels (55 % here). The entire methodology is validated using simulations. For the data, using the foreground avoidance technique, we obtain a $2\,\sigma$ upper limit of $\Delta^2(k) \leq (133.97)^2\,\mathrm{mK}^2$ for the 21-cm brightness temperature fluctuation at $k = 0.347\,\mathrm{Mpc}^{-1}$. This corresponds to $[\Omega_{HI}\ b_{HI}] \leq 0.23$, where Ω_{HI} and b_{HI} respectively denote the cosmic H_I mass density and the H_I bias parameter. A previous work has analyzed 8 MHz of the same data at $z = 2.19$, and reported $\Delta^2(k)le(61.49)^2\,\mathrm{mK}^2$ and $[\Omega_{HI}\ b_{HI}] \leq 0.11$ at k=1 Mpc^{-1}. The upper limits presented here are still orders of magnitude larger than the expected signal corresponding to $[\Omega_{HI} \sim 10^{-3}$ and $b_{HI}] \sim 2$. This work has been done in collaboration with Srijita Pal, Kh. Md. Asif Elahi, Somnath Bharadwaj, Sk. Saiyad Ali et al.

Towards 21-cm intensity mapping at $z = 2.28$ with uGMRT using the tapered gridded estimator II: Cross-polarization power spectrum

Neutral hydrogen (H_I) 21-cm intensity mapping (IM) offers an efficient technique for mapping the large-scale structures in the universe. We introduce the 'Cross' Tapered Gridded Estimator (Cross TGE), which cross-correlates two cross-polarizations (RR and LL) to estimate the multi-frequency angular power spectrum (MAPS) $C_\ell(\Delta\nu)$. We expect this to mitigate several effects like noise bias, calibration errors etc., which affect the 'Total' TGE which combines the two polarizations. Here we apply the Cross TGE on a 24.4 MHz bandwidth uGMRT Band 3 data centred at 432.8 MHz aiming H_I IM at $z = 2.28$. The measured $C_\ell(\Delta\nu)$ is modelled to yield maximum likelihood estimates of the foregrounds and the spherical power spectrum $P(k)$ in several k bins. Considering the mean squared brightness temperature fluctuations, we report a 2σ upper limit $\Delta^2_{UL}(k) \leq (58.67)^2\,\mathrm{mK}^2$ at $k = 0.804\,\mathrm{Mpc}^{-1}$ which is a factor of 5.2 improvement on our previous estimate based on the Total TGE. Assuming that the H_I traces the underlying matter distribution, we have modelled $C_\ell(\Delta\nu)$ to simultaneously estimate the foregrounds and $[\Omega_{HI}b_{HI}]$ where Ω_{HI} and b_{HI} are the H_I density and linear bias parameters respectively. We obtain a best fit value of $[\Omega_{HI}b_{HI}]^2 = 7.51 \times 10^{-4} \pm 1.47 \times 10^{-3}$ which is consistent with noise. Although the 2σ upper limit $[\Omega_{HI}b_{HI}]_{UL} \leq 0.061$ is ~ 50 times larger than the

expected value, this is a considerable improvement over earlier works at this redshift. This work has been done in collaboration with Kh. Md. Asif Elahi, Somnath Bharadwaj, Abhik Ghosh, Srijita Pal, et al.

Suman Ghosh

Geodesic congruences in 5D warped Ellis-Bronnikov spacetimes

We study the timelike geodesic congruences in the generalised Ellis-Bronnikov spacetime (4D-GEB) and in recently proposed 5D model where a 4D-GEB is embedded in a warped geometry (5D-WGEB) and conduct a comparative study. Analytical expressions of ESR variables (for 4D geometries) are found which reveal the role of the wormhole parameter. In more general 4D and 5D scenarios geodesic equation, geodesic deviation equation and Raychaudhuri equations are solved numerically. The evolution of cross-sectional area of the congruences of timelike geodesics (orthogonal to the geodesic flow lines) projected on 2D-surfaces yield an interesting perspective and shows the effects of the wormhole parameter and growing/decaying warp factors. The presence of warping factor triggers rotation or accretion even in the absence of initial congruence rotation. The presence of rotation in the congruence is also found to be playing a crucial role which we discuss in detail. This work has been done in collaboration with Vivek Sharma.

Geodesics in generalised Ellis Bronnikov spacetime embedded in warped 5D background

We study the particle trajectories in the recently proposed five dimensional warped (generalized) Ellis-Bronnikov spacetime (5D-WGEB) (which does not require exotic matter) as well as it's four dimensional counterpart (4D-GEB) in detail and conduct a comparative study. Analytical approach provides conditions which determines three types of trajectories (trapped, returning and crossing) for both 4D and 5D spacetimes. Notably in 5D geometry existence of trapped trajectories become highly sensitive to the initial conditions. We have solved the timelike geodesic equations numerically and presented the trajectories graphically along with corresponding geodesic potentials. We thus distinguished the roles of the so-called wormhole parameter and the warping factor regarding their effects on the trajectories and embedding as such. Interestingly, the 5D-WGEB model shows the localization of massive particles around the location of the brane for growing warp factor and runaway trajectories for decaying warp factor. This work has been done in collaboration with Vivek Sharma.

Sushant G. Ghosh

*Tests of Loop Quantum Gravity from the Event Horizon Telescope Results of Sgr A**

The Event Horizon Telescope (EHT) collaboration's image of the compact object at the galactic center is the first direct evidence of the supermassive black hole (BH) Sgr A*. The shadow of Sgr A* has an angular diameter $d_{sh} = 48.7 \pm 7\,\mu$as with fractional deviation from the Schwarzschild BH shadow diameter $\delta = -0.08^{+0.09}_{-0.09}, -0.04^{+0.09}_{-0.10}$ (for the VLTI and Keck mass-to-distance ratios). Sgr A*'s shadow size is within 10% of Kerr predictions, equipping us with yet another tool to analyze gravity in the strong-field regime, including testing loop quantum gravity (LQG). We use Sgr A*'s shadow to constrain the metrics of two well-motivated LQG-inspired rotating BH (LIRBH) models characterized by an additional deviation parameter L_q, which recover the Kerr spacetime in the absence of quantum effects ($L_q \to 0$). When increasing the quantum effects through L_q, the shadow size increases monotonically, while the shape gets more distorted, allowing us to constrain the fundamental parameter L_q. We use the astrophysical observables shadow area A and oblateness D to estimate the BH parameters. It may be useful in extracting additional information about LIRBHs. While the EHT observational results completely rule out the wormhole region in the LIRBH-2, a substantial parameter region of the generic BHs in both models agrees with the EHT results. We find that the upper bounds on L_q obtained from the shadow of Sgr A* —$L_q \lesssim 0.0423$ and $L_q \lesssim 0.0821$ for the two LIRBHs, respectively—are more stringent than those obtained from the EHT image of M87*. This work has been done in collaboration with Misba Afrin and Sunny Vagnozzi.

An Upper Limit on the Charge of the Black Hole Sgr A from EHT Observations*

The Event Horizon Telescope (EHT) recently released an image of the supermassive black hole Sgr A* showing an angular shadow diameter $d_{sh} = 48.7 \pm 7\,\mu$as and Schwarzschild shadow deviation $\delta = -0.08^{+0.09}_{-0.09}$ (VLTI), $-0.04^{+0.09}_{-0.10}$ (Keck) using a black hole mass $M = 4.0^{+1.1}_{-0.6} \times 10^6 M_\odot$. The EHT image of

Sgr A* is consistent with a Kerr black hole's expected appearance, and the results directly prove the existence of a supermassive black hole at the center of the Milky Way. Here, we use the EHT observational results for Sgr A* to investigate the constraints on its charge with the aid of Kerr-like black holes, paying attention to three leading rotating models, namely Kerr–Newman, Horndeski, and hairy black holes. Modeling the supermassive black hole Sgr A* as these Kerr-like black holes, we observe that the EHT results of Sgr A* place more strict upper limits on the parameter space of Kerr–Newman and Horndeski black holes than those placed by the EHT results for M87*. A systematic bias analysis reveals that, observational results of future EHT experiments place more precise limits on the charge of black hole Sgr A*. Thus, the Kerr-like black holes and Kerr black holes are indiscernible in a substantial region of the EHT-constrained parameter space; the claim is substantiated by our bias analysis. This work has been done in collaboration with Misba Afrin.

Umananda D. Goswami

Quasinormal Modes and Hawking Radiation Sparsity of GUP corrected Black Holes in Bumblebee Gravity with Topological Defects

We have obtained the Generalized Uncertainty Principle (GUP) corrected de Sitter and anti-de Sitter black hole solutions in bumblebee gravity with a topological defect. We have calculated the scalar, electromagnetic and gravitational quasinormal modes for the both vanishing and non-vanishing effective cosmological constant using Padé averaged sixth order WKB approximation method. Apart from this, the time evolutions for all three perturbations are studied, and quasinormal modes are calculated using the time domain profile. We found that the first order and second order GUP parameters α and β, respectively have opposite impacts on the quasinormal modes. The study also finds that the presence of a global monopole can decrease the quasinormal frequencies and the decay rate significantly. On the other hand, Lorentz symmetry violation has noticeable impacts on the quasinormal frequencies and the decay rate. We have studied the greybody factors, power spectrum and sparsity of the black hole with the vanishing effective cosmological constant for all the three perturbations. The presence of Lorentz symmetry breaking and the GUP parameter α decrease, while other GUP parameter β and the presence of global monopole increase the probability of Hawking radiation to reach the spatial infinity. The presence of Lorentz violation can make the black holes less sparse, while the presence of a global monopole can increase the sparsity of the black holes. Moreover, we have seen that the black hole area quantization rule is modified by the presence of Lorentz symmetry breaking. This work has been done in collaboration with Dhruba Jyoti Gogoi.

Strange stars in $f(\mathcal{R})$ gravity Palatini formalism and gravitational wave echoes from them

The compact stars are promising candidates associated with the generation of gravitational waves (GWs). In this work, we study a special type of compact stars known as strange stars in the $f(\mathcal{R})$ gravity Palatini formalism. Here we consider three promising $f(\mathcal{R})$ gravity models viz., Starobinsky, Hu-Sawicki and Gogoi-Goswami models in the domain of MIT Bag model and linear equations of state (EoSs). We compute the stellar structures numerically and constrained the $f(\mathcal{R})$ model parameters with a set of probable strange star candidates. The study shows that the consideration of stiffer MIT Bag model and linear EoSs within a favourable set of $f(\mathcal{R})$ gravity model parameters may result in strange stars with sufficient compactness to produce echoes of GWs. Thus, we have computed the GWs echo frequencies and characteristic echo times for such stars. It is found that in compliance with the experimentally obtained possible strange star candidates, the obtained GW echo frequencies for all the models are in the range of $65 - 85$ kHz. This work has been done in collaboration with Jyatsnasree Bora, and Dhruba J. Gogoi. .

Shivappa B. Gudennavar

Spectral characteristics of the black hole binary 4U 1957 + 115: a multi mission perspective

We report spectral analysis of the persistent black hole X-ray binary, 4U 1957 + 115, using AstroSat, Swift, and NuSTAR observations carried out between 2016 and 2019. Modelling with a disc emission, thermal Comptonization, and blurred reflection components revealed that the source was in the high-soft state with the disc flux ∼87 per cent of the total and high-energy photon index ∼2.6. There is an evidence that either the inner disc radius varied by ∼25 per cent or the colour hardening factor changed by ∼ per cent. The values of the inner disc radius imply that for a non-spinning black hole, the black hole mass is < 7 $M_\odot$ and the

source is located $> 30kpc$ away. On the other hand, a rapidly spinning black hole would be consistent with the more plausible black hole mass of ¡ 10 $M_\odot$ and a source distance of ∼10 kpc. Fixing the distance to 10 kpc and using a relativistic accretion disc model, constrained the black hole mass to 6 $M_\odot$ and inclination angle to 72°. A positive correlation is detected between the accretion rate and inner radii or equivalently between the accretion rate and colour factor. This work has been done in collaboration with S. P. Mudambi, Ranjeev Misra, and S.G. Bubbly.

Spectro-temporal and type I X-ray burst analysis of GX 3+1 using AstroSat observations

GX 3+1, an atoll type neutron star low-mass X-ray binary, was observed four times by Soft X-ray Telescope and The Large Area X-ray Proportional Counters on-board *AstroSat* between October 5, 2017 and August 9, 2018. The hardness-intensity-diagram of the source showed it to be in the soft spectral state during all the four observations. The spectra of the source could be adequately fit with a model consisting of blackbody (`bbody`) and power-law (`powerlaw`) components. This yielded the blackbody radius and mass accretion rate to be ∼8 km and $\sim 2 \times 10^{-9}$ $M_\odot$ y^{-1}, respectively. In one of the observations, a Type I X-ray burst having a rise and e-folding time of 0.6 and 5.6 s, respectively, was detected. Time-resolved spectral analysis of the burst showed that the source underwent a photospheric radius expansion. The radius of the emitting blackbody in GX 3+1 and its distance were estimated to be $9.19^{+0.97}_{-0.82}$ km and $10.17^{+0.07}_{-0.18}$ kpc, respectively. Temporal analysis of the burst yielded upper limits of the fractional RMS amplitude of 7%, 5% and 6% during burst start, burst maximum and right after the radius expansion phase, respectively. This work has been done in collaboration with Neal Titus Thomas, and S. G.Bubbly.

Sarbari Guha

How appropriate are the gravitational entropy proposals for traversable wormholes?

In this paper we have examined the validity of some proposed definitions of gravitational entropy (GE) in the context of traversable wormhole solutions of the Einstein field equations. Here we have adopted two different proposals of GE and checked for their applicability in the case of these wormholes. The first one is the phenomenological approach proposed by Rudjord et al [Phys. Scr. 77:055901, 2008] and expanded by Romero et al in [Int. J. Theor. Phys. 51:925, 2012], which is a purely geometric method of measuring gravitational entropy. The latter one is the Clifton-Ellis-Tavakol (CET) proposal [Class. Quantum Grav. 30:125009, 2013] for the gravitational entropy which arises in relativistic thermodynamics, and is based on the Bel-Robinson tensor, that represents the effective super-energy-momentum tensor of free gravitational fields. Considering some of the Lorentzian traversable wormholes along with the Brill solution for NUT wormholes and the AdS wormholes, we have evaluated the gravitational entropy for these systems. Incidentally, the application of the CET proposal can provide unique gravitational entropies for spacetimes of Petrov type D and N only, whereas the geometric method can be applied to almost every kind of spacetime, although it has no relation with thermodynamics. For any traversable wormhole to be physically realistic, it should have a viable GE. We found that the GE proposals do give us a consistent measure of GE in several of them. This means that the existence of a viable gravitational entropy strictly depends on its definition. This work has been done in collaboration with Samarjit Chakraborty, and Rituparno Goswami.

Density Perturbation and Cosmological Evolution in the Presence of Magnetic Field in f(R) Gravity Models

In this paper, we have investigated the density perturbations and cosmological evolution in the FLRW universe in the presence of a cosmic magnetic field, which may be assumed to mimic primordial magnetic fields. Such magnetic fields have sufficient strength to influence galaxy formation and cluster dynamics, thereby leaving an imprint on the CMB anisotropies. We have considered the FLRW universe as a representative of the isotropic cosmological model in the $1 + 3$ covariant formalism for $f(R)$ gravity. The propagation equations have been determined and analyzed, where we have assumed that the magnetic field is aligned uniformly along the x-direction, resulting in a diagonal shear tensor. Subsequently, the density perturbation evolution equations have been studied, and the results have been interpreted. We have also indicated how these results change in the general relativistic case and briefly mentioned the expected change in higher-order gravity theories. This work has been done in collaboration with Samarjit Chakraborty.

Mamta Gulati

RAD@home citizen science discovery of an active galactic nucleus spewing a large unipolar radio bubble on to its merging companion galaxy

Active galactic nucleus (AGN) feedback during galaxy merger has been the most favoured model to explain black hole-galaxy co-evolution. However, how the AGN-driven jet/wind/radiation is coupled with the gas of the merging galaxies, which leads to positive feedback, momentarily enhanced star formation, and subsequently negative feedback, a decline in star formation, is poorly understood. Only a few cases are known where the jet and companion galaxy interaction leads to minor off-axis distortions in the jets and enhanced star formation in the gas-rich minor companions. Here, we briefly report one extraordinary case, RAD12, discovered by RAD@home citizen science collaboratory, where for the first time a radio jet-?driven bubble (137 kpc) is showing a symmetric reflection after hitting the incoming galaxy which is not a gas-rich minor but a gas-poor early-type galaxy in a major merger. Surprisingly, neither positive feedback nor any radio lobe on the counter jet side, if any, is detected. It is puzzling if RAD12 is a genuine one-sided jet or a case of radio lobe trapped, compressed and re-accelerated by shocks during the merger. This is the first imaging study of RAD12 presenting follow-up with the Giant Metrewave Radio Telescope, archival MeerKAT radio data and Canada-France-Hawaii Telescope optical data. This work has been done in collaboration with Ananda Hota, Pratik Dabhade, Sravani Vaddi, Chiranjib Konar, Sabyasachi Pal et al.

Enhanced $m = 1$ WKB instabilities in nearly Keplerian stellar discs due to the presence of gas

Dynamical evolution of galaxies is a complex process, especially the centers. Gravitationally coupled gas and stellar discs have been observed to coexist in the galactic discs, including at the center of galaxies. The present work, provide a simple analytic model of nearly Keplerian modes, for co-rotating gravitationally coupled gaseous and stellar discs. We restrict our analysis to 'slow modes'; their eigenfrequencies being much smaller than the Keplerian orbital frequency to the disc. The dispersion relation using the Wentzel-Kramers-Brillouin (WKB) approximation is formulated and the stability of modes is explored. The presence of gas is found to enhance the instability and slow modes exists only for azimuthal wavenumber, $m = 1$ for the continuum disc. We also analyze the nature of discrete eigen-spectra by quantizing the modes using the Bohr-Sommerfeld quantization condition. The Presence of gas supports the formation of modes with higher temporal frequency and larger wavelength, making them large scale and long-lived. We find that discrete spectra is absent if the ratio of gas mass to stellar mass in galactic disc is greater than 0.1. Though simplified our analysis gives a physically relevant framework for the formation and existence of eccentric disc at the center of galaxies without invoking any external factor. It hence paves a way to explaining the observed asymmetries at the centers of galaxies without provoking the need of continuous source of generation of perturbation. This work has been done in collaboration with Meenu Prajapati.

Priya Hasan

The enhanced YSO population in Serpens

The Serpens Molecular Cloud is one of the most active sites of ongoing star formation at a distance of about 300 pc, and hence is very well-suited for studies of young low-mass stars and sub-stellar objects. In this paper, for the Serpens star forming region, we find potential members of the Young Stellar Objects population from the Gaia DR3 data and study their kinematics and distribution. We compile a catalog of 656 YSOs from available catalogs ranging from X-ray to the infrared. We use this as a reference set and cross-match it to find 87 Gaia DR3 member stars to produce a control sample with revised parameters. We queried the DR3 catalog with these parameters and found 1196 stars. We then applied three different density-based machine learning algorithms (DBSCAN, OPTICS and HDBSCAN) to this sample and found potential YSOs. The three clustering algorithms identified a common set of 822 YSO members from Gaia DR3 in this region. We also classified these objects using 2MASS and WISE data to study their distribution and the progress of star formation in Serpens. This work has been done in collaboration with Mudasir Raja, Md Mahmudunnobe, and S N 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 work has been done in collaboration with P. Nagamani, and S.N. Hasan.

Golam Mortuza Hossain

Equation of states in the curved spacetime of slowly rotating degenerate stars

We compute the equation of state for an ensemble of degenerate fermions by using the curved spacetime of a slowly rotating axially symmetric star. We show that the equation of state computed in such curved spacetime depends on the gravitational time dilation as well as on the dragging of inertial frames, unlike an equation of state computed in a globally flat spacetime. The effect of gravitational time dilation leads to a significant enhancement of the maximum mass limit of a degenerate neutron star. However, such an enhancement due to the frame-dragging effect is extremely small. Nevertheless, in general relativity the frame-dragging effect is crucial for computing angular momentum of the star which is also shown to be enhanced significantly due to the usage of curved spacetime in computing the equation of state. This work has been done in collaboration with S. Mandal.

Chetna Jain

Eclipse Timings of the LMXB XTE J1710–281 : Discovery of a third orbital period glitch

We present an updated measurement of orbital period evolution of LMXB XTE J1710–281 by using eclipse timing technique. Using data obtained with XMM–Newton, Suzaku, RXTE, Chandra, and AstroSat observatories, we report 21 new measurements of X-ray mid-eclipse times. We have discovered a third orbital period glitch in XTE J1710–281 with an F-test false alarm probability of ∼0.7 per cent for occurrence of the third glitch and report detection of four distinct epochs of orbital period in this system. This work presents a more robust estimation of occurrence of the second orbital period glitch. However, the epoch of occurrence of the third glitch is poorly constrained, between MJD 55726 and 56402. We have put lower limits of 1.48, 0.97, and 0.45 ms, on sudden changes in orbital period between the successive epochs. We discuss the implications of our findings in context of magnetic nature of the companion star and possible scattering events with circumbinary objects around this binary system. This work has been done in collaboration with Rahul Sharma and Biswajit Paul.

Discovery of cyclotron and narrow Fe K_α lines in HMXB GRO J1750–27

We report on the timing and spectral analysis of transient Be X-ray pulsar GRO J1750–27 using the Nuclear Spectroscopic Telescope Array(NuSTAR) observation from 2021 September. This is the fourth outburst of the system since 1995. The NuSTAR observation was performed during the rising phase of the outburst. Pulsations at a period of 4.450710(1) s were observed in the 3–60 keV energy range. The average pulse profile comprised of a broad peak with a weak secondary peak, which evolved with energy. We did not find any appreciable variation in the X-ray emission during this observation. The broad–band phase–averaged spectrum is described by a blackbody, a power law, or Comptonization component. We report the discovery of Fe K_α line at 6.4 keV, along with the presence of two cyclotron resonant scattering features of around 36 and 42 keV. These lines indicate a magnetic field with the strength of $3.7^{+0.1}_{-0.3} \times 10^{12}$ and $4.4 \pm 0.10 \times 10^{12}$ G for the neutron star. We have estimated a source distance of ∼13.6–16.4 kpc based on the accretion-disc torque models. This work has been done in collaboration with Prince Sharma and Anjan

Dutta.

Jessy Jose

Tracers of Dense Gas in the Outer Galaxy

We have mapped HCN and HCO+ line emission toward a sample of seven star-forming regions (with $12 + \log[O/H]$ range from 8.34 to 8.69) in the outer Milky Way (Galactocentric distance > 9.5 kpc), using the 14-meter radio telescope of the Taeduk Radio Astronomy Observatory (TRAO). We compare these two molecular lines with other conventional tracers of dense gas, millimeter-wave continuum emission from dust and extinction thresholds ($A_V \geq 8$ mag), inferred from the ^{13}CO line data. HCN and HCO+ correlate better with the millimeter emission than with the extinction criterion. A significant amount of luminosity comes from regions below the extinction criterion and outside the millimeter clump for all the clouds. The average fraction of HCN luminosity from within the regions with $A_V \geq 8$ mag is 0.343 ± 0.225; for the regions of millimeter emission, it is 0.478 ± 0.149. Based on a comparison with column density maps from Herschel, HCN and HCO+ trace dense gas in high column density regions better than does ^{13}CO. HCO+ is less concentrated than HCN for outer Galaxy targets, in contrast with the inner Galaxy sample, suggesting that metallicity may affect the interpretation of tracers of dense gas. The conversion factor between the dense gas mass and line luminosities of HCN and HCO+, when integrated over the whole cloud, is comparable with factors used in extragalactic studies. This work has been done in collaboration with Sudeshna Patra, Neal J. Evans II, Kee-Tae Kim, and et al.

A novel survey for young substellar objects with the W-band filter IV: detection and characterization of low-mass brown dwarfs in Serpens Core

We present spectroscopic confirmation of nine M5 or later Serpens Core candidate members, identified using a combination of CFHT WIRCam photometry and IRTF SpeX spectroscopy. Through spectral fitting, we find that the latest of these nine candidate members is best fit by an L0 spectral standard (in the range of M8-L2), implying a mass of $\sim$ 0.01-0.035M$\odot$. If confirmed as a cluster member, this would be one of the lowest mass Serpens Core objects ever discovered. We present analysis of the physical properties of the sample, as well as the likely membership of the candidate Serpens Core members. This work has been done in collaboration with Sophie Dubber, Beth Biller, Loic Albert, Michael Liu, and et al.

Minu Joy

Evolutionary optimization of cosmological parameters using metropolis acceptance criterion

A novel evolutionary method that takes leverage from the MCMC method that can be used for constraining the parameters and theoretical models of Cosmology is proposed. Unlike the MCMC technique, which is essentially a non-parallel algorithm by design, the newly proposed algorithm is able to obtain the full potential of multi-core machines. With this algorithm, we could obtain the best-fit parameters of the ΛCDM cosmological model and identify the discrepancy in the Hubble parameter H_0. We discuss the design principle of this novel approach and also the results from the analysis of Pantheon, OHD and Planck datasets are reported. The estimation of parameters shows significant consistency with the previously reported values as well as a higher computational performance compared to the other similar exercises. This work has been done in collaboration with Supin P Surendran.

Gravitational wave production after inflation for a hybrid inflationary model

A cosmological scenario with a stochastic background of gravitational waves sourced by the tensor perturbation due to a hybrid inflationary model with cubic potential is studied. Gravitational wave spectrum of this stochastic background, for large-scale CMB modes, $10^{-4}Mpc^{-1}$ to $1Mpc^{-1}$ is discussed. The present-day energy spectrum of gravitational waves $\Omega_0^{gw}(f)$ is sensitively related to the tensor power spectrum and r which is, in turn, dependent on the unknown physics of the early cosmos. This uncertainty is characterized by two parameters: $n_t\hat{(}f)$ logarithmic average over the primordial tensor spectral index and $w\hat{(}f)$ logarithmic average over the effective equation of state parameter. Thus, exact constraints in the $w\hat{(}f)$, $n_t\hat{(}f)$ plane can be obtained by comparing theoretical constraints of our model on r and $\overset{gw}{0}(f)$. We obtain a limit on $\hat{w}(10^{-15}Hz) < 0.33$ around the modes probed by CMB scales. This work has been done in collaboration with Rinsy Thomas.

Mehedi Kalam

Lorentzian wormholes in an emergent universe

A non-singular emergent universe (EU) scenario within the realm of standard Relativistic physics requires a generalization of the equation of state (EoS) connecting the pressure and energy density. This generalized EoS is capable of describing a composition of exotic matter, dark energy and cosmological dust matter. Since the EU scenario is known to violate the null energy condition (NEC), we investigate the possibility of presence of static, spherically symmetric and traversable Lorentzian wormholes in an EU. The obtained shape function is found to satisfy the criteria for wormhole formation, besides the violation of the NEC at the wormhole throat and ensuring traversability such that tidal forces are within desirable limits. Also, the wormhole is found to be stable through linear stability analysis. Most importantly, the numerical value of the EU parameter B as estimated by our wormhole model is in agreement with and lies within the range of values as constrained by observational data in a cosmological context. Also, the negative sign of the second EU parameter A as obtained from our wormhole model is in agreement with the one required for describing an EU, which further indicates on the existence of such wormholes in an EU without accounting for any additional exotic matter field or any modification to the gravitational sector. This work has been done in collaboration with Rikpratik Sengupta, Shounak Ghosh, and B.C.Paul.

Wormhole in Milky Way galaxy with global monopole charge

Wormholes are tunnels or short-cuts in space-time, and their existence is very important for human civilization to express the vastness of space and time. So, it is necessary to analyze our own Milky Way galaxy if it can harbour any wormhole. This work is dedicated to the existence of wormhole geometry(at least theoretically) in the bulge and halo of the Milky Way Galaxy. The structure and existence of wormholes are verified in both the bulge and the halo region of the Milky Way galaxy (MWG). Different dark matter profiles like pseudo-isothermal, NFW and Universal Rotational Curve (URC) are analyzed to harbour these cosmic tunnels. Three kinds of redshift functions are used for each dark matter profile with the global monopole charge to cover all the possibilities of MWG supporting wormhole geometry. This work has been done in collaboration with Priyam Das.

Arun Kenath

From maximum force to the field equations of general relativity and implications

There are at least two ways to deduce Einstein's field equations from the principle of maximum force $c^4/4G$ or from the equivalent principle of maximum power $c^5/4G$. Tests in gravitational wave astronomy, cosmology, and numerical gravitation confirm the two principles. Apparent paradoxes about the limits can all be resolved. Several related bounds arise. The limits illuminate the beauty, consistency and simplicity of general relativity from an unusual perspective. This work has been done in collaboration with Christoph Schiller, and C. Sivaram.

MONG: An extension to galaxy clusters

The presence of dark matter (DM), though well established by indirect evidence, is yet to be observed directly. Various DM detection experiments running for several years have yielded no positive results. In view of these negative results, we had earlier proposed alternate models by postulating a minimum gravitational field strength (minimum curvature) and a minimum acceleration. These postulates led to the modified Newtonian dynamics and modified Newtonian gravity (MONG). The observed flat rotation curves of galaxies were also accounted for through these postulates. Here, we extend these postulates to galaxy clusters and model the dynamical velocity-distance curve for a typical cluster such as the Virgo cluster. The radial velocities of galaxies in the Virgo cluster are also obtained through this model. Observations show an inconsistency in the Hubble flow at a mean cluster distance of 17 Mpc, which is expected in regions of high matter density. This decrease in velocity is predicted by our model of modified gravity (MONG). The radial velocity versus distance relation for galaxies in the Virgo cluster obtained using MONG is in agreement with observations. This work has been done in collaboration with Louise Rebecca, and C. Sivaram.

Nishikanta Khandai

The Dark Matter Halos of HI-Selected Galaxies

We present the neutral hydrogen mass (M_{HI}) function (HIMF) and velocity width (w_{50}) function (HIWF) based on a sample of 7857 galaxies from the 40% data release of the ALFALFA survey ($\alpha.40$). The low mass (velocity width) end of the HIMF (HIWF) is dominated

by the blue population of galaxies whereas the red population dominates the HIMF (HIWF) at the high mass (velocity width) end. We use a deconvolution method to estimate the HI rotational velocity ($V_{\rm rot}$) functions (HIVF) from the HIWF for the total, red, and blue samples. The HIWF and HIVF for the red and blue samples are well separated at the knee of the function compared to their HIMFs. We then use recent stacking results from the ALFALFA survey to constrain the halo mass (M_{halo}) function of HI-selected galaxies. This allows us to obtain various scaling relations between M_{HI} – $\omega 50$ – V_{rot} – M_{halo}, which we present. The M_{HI}-M_{halo} relation has a steep slope ~ 2.10 at small masses and flattens to ~ 0.34 at masses larger than a transition halo mass, $\log_{10}(M_{\rm ht}h_{70}^2/M_\odot) = 10.62$. Our scaling relation is robust and consistent with a volume-limited sample of $\alpha.40$. The M_{HI} – M_{halo} relation is qualitatively similar to the $M_\star$– M_{halo} relation but the transition halo mass is smaller by ~ 1.4 dex compared to that of the $M_\star$-M_{halo} relation. Our results suggest that baryonic processes like heating and feedback in larger mass halos suppress HI gas on a shorter time scale compared to star-formation. This work has been done in collaboration with S. Dutta, S. Rana.

Ram Kishor

2D and 3D axi-symmetric horseshoe periodic orbits about Lagrangian points: A global grid search approach

This paper presents the numerical exploration of planar as well as spatial periodic horseshoe orbits about Lagrangian points in the framework of restricted three-body problem with radiation pressure and albedo as perturbations. The global grid search technique for obtaining both types of periodic horseshoe orbits is described. Further, several families of horseshoe orbits are obtained and then the orbital behaviour of each periodic orbit is investigated. By global grid search method, spatial axi-symmetric horseshoe orbits and their families are obtained via pseudo-arclength continuation. Interestingly, new forms of spatial horseshoe orbits are constructed and their orbital properties are analysed. Moreover, it is found that stable horseshoe orbits exists for different range of in planar as well as in spatial case. Using parameter continuation, the effect of radiation pressure and albedo are discussed for the evolution of horseshoe orbits and found that the radiation pressure affects the shape of horseshoe orbits more then that of albedo. These results are helpful to analyse more generalized problem with other perturbations. This work has been done in collaboration with Saleem Yousuf.

Floquet stability analysis of equilibrium points and numerical exploration of pulsating zero-velocity curves and Newton-Raphson basins of attraction

An important and pivot aspect of a dynamical system is the stability property and its range, which play a crucial role towards the stabilisation of a mission design. Present paper deals with Floquet stability analysis of equilibrium points and estimation of pulsating zero velocity curves and Newton–Raphson basins of attraction associated to these equilibrium points under the radiation pressure effect in the photo-gravitational planar elliptic restricted four body problem. Floquet stability test for the equilibrium points is performed with the help of the transition curves, which are generated under the influence of radiation pressure. It is noticed that stability range of the respective equilibrium points have deviated due to radiation pressure. To observe the possible regions of motion for restricted body, the pulsating zero velocity curves are numerically explored after establishing an invariant relation. It is found that not only the radiation parameter but also eccentricity and true anomaly reflect a considerable impact on the shape and size of forbidden regions. To see the tendency of randomly selected points in the phase space, Newton–Raphson basins of attraction associated to each attractor are estimated and effects of perturbing parameters are analysed. It is observed that effects of radiation and mass parameters are considerable however, that of eccentricity and true anomaly are negligible. Moreover, from probability distribution bar diagram, most probable number of iterations is 10 for the case when two primaries are of equal masses and third one is different, whereas it is 20 for the case when all primaries are of identical mass. These results will be helpful to study the generalised problem along with other kind of perturbations. This work has been done in collaboration with Poonam Meena.

Nagendra Kumar

Effect of Heating-Cooling Imbalance on Slow Mode with Time Dependent Background Temperature

We study the effect of heating-cooling imbalance on slow magnetohydrodynamic waves in solar coronal loops with time varying background temperature in the presence

of thermal conduction, optically thin radiation and heating. The MHD equations governing the plasma motion are solved numerically to examine the effects of heating-cooling imbalance on slow waves in the presence of thermal conduction and radiation. It is found that amplitude of perturbed velocity decreases in case of increasing background temperature, whereas the perturbed velocity amplitude increases in case of decaying background temperature. The heating-cooling imbalance influences the damping of slow waves. Damping of waves is stronger for characteristic time $\tau = 1000s$ than the damping for $\tau = 3000s$ in both time varying back ground temperature plasmas. This work has been done in collaboration with Anil Kumar.

R. K. Sunil Kumar

Combined Use of Nonlinear Measures for Analyzing Pathological Voices

Automatic voice pathology detection enables an objective assessment of pathologies that influence the voice production strategy. By utilizing the conventional pipeline model as well as the modern deep learning-centric end-to-end methodology, numerous pathological voice analysing techniques have been developed. The conventional methodology is still a valid choice owing to the lack of enormous amounts of training data in the study region of pathological voice. In the meantime, obtaining higher precision, higher accuracy, and stability is still a complicated task. Therefore, by amalgamating the nonlinear measure, the pathological voices are analysed to abate such risks. The viability of six nonlinear discriminating measures derived from the phase space realm, involving healthy and pathological voice signals, is studied in this work. The analysed parameters are Singularity spectrum coefficients (α_{min} $\alpha_{max} Y_1 and Y_2$). Correlation entropy at optimum embedding dimension (K_{2m}) and correlation dimension at optimum embedding dimension (D_{2m}). Analyzing the pathological voices with better accuracy rates is the major objective of the proposed methodology. Here, the Support Vector Machine (SVM) was utilized as the classifier. Experimentations were performed on VOiceICarfEDerico (VOICED) databases subsuming 208 healthy, as well as pathological voices, amongst these 50 samples, were utilized. Here, the model obtained 97% of accuracy with 99% as of the classifier with Gaussian kernel function. Therefore, to differentiate normal as well as pathological subjects, the six proposed characteristics are highly beneficial; in addition, they will be supportive in pathology diagnosis. This work has been done in collaboration with K. M. Muraleedharan, K. T. Bibish Kumar, and Sunil John.

Sanjay Kumar

Magnetohydrodynamics evolution of three-dimensional magnetic null in NOAA active region 11515 initiated using non-force-free field extrapolation

Magnetohydrodynamics simulation of active region NOAA 11515 is performed to examine the initiation of the M5.6 flaring event that starts around 10:43 UT on 2012 July 2. The simulation is conducted using an extrapolated non-force-free magnetic field generated from the photospheric vector magnetogram of the active region as the initial magnetic field. The initial magnetic field shows the presence of a three-dimensional (3D) magnetic null topology overlying a filament and a low-lying magnetic flux rope, observed in 304 Å and 131 Å respectively. The simulated dynamics, triggered by the initial Lorentz force, lead to the bifurcations of the flux rope, which, is similar to the observed bifurcation in the 131 Å brightenings. Additionally, the rope exhibits a rise and reconnects at the 3D null. These reconnections convert field lines of the rope into the anchored outer spine of the 3D null — possibly explaining the nearby confined C-class flare. Further, the results show that the field lines of the flux rope reach the vicinity of the filament and become non-parallel to the field lines of the filament. This initiates the reconnections between the rope and the field lines of the filament — activating the filament for the eruption. This interesting interaction of the flux rope and filament contributes to the onset of the M-class flare. This work has been done in collaboration with Avijeet Prasad, Ranadeep Sarkar, and R. Bhattacharyya.

Vinjanampaty Madhurima

Hydrogen-bonded networks in alcohol-acetone binary mixtures: 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. In order to have a better understanding of this phenomenon, a systematic molecular dynamics study of binary mixtures of acetone with eight primary alcohols (R-OH, with R=1 to 8) was undertaken. The structure of the binary systems is studied using radial distribution function, hydrogen

bond statistics, and graph theoretical approach. Two distinct features are observed. Firstly, the bunching of R=(1, 2), R=(3, 4, 6), and R=(5, 7, 8)-acetone mixture in their hydrogen bond characteristics. Secondly, the number of alcohol-acetone hydrogen bonds is more for R=(3, 4, 6) and the alcohol-alcohol hydrogen bonds for the rest, indicating a preferential bonding of R=(3, 4, 6) alcohols with acetone when compared to the rest. With an increase in acetone concentration, the average degree of association decreases for all systems, showing an overall decrease in hydrogen bond multimer structures. The hydrogen bond networks are visualized using graph theory. This work has been done in collabration with Abdulkareem U, and Thejus R Kartha.

Hydrogen bonding in 1-Propanol-Ethanol Binary Mixture: Experimental 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 collabration with Swathi P. V., Abdulkareem U, and Thejus R Kartha.

Manzoor A. Malik

Imager observation of Concentric Mesospheric Gravity Waves over Srinagar, Jammu and Kashmir, India

Using the NARL airglow imager in the Indian subtropical station of Srinagar, Kashmir, India, we report the characteristics of the concentric deformed circular pattern of gravity waves detected at 85 km height. OH molecular emission intensities from the height of 85 km as observed by the imager in the wide band optical filter of centre wavelength of 840 nm show concentric deformed circular gravity waves drifting northwestward. Using Atmospheric Infrared Sounder (AIRS) image at the centre wavelength of 8.1 µm, deep convective activity around the imager site in the lower atmosphere is recognized as the source mechanism of the observed concentric gravity waves in the mesosphere. The determined phase speed, direction and period of these concentric gravity waves (CGWs) is 47 m/s, 150° north of east and 10 min (intrinsic period 8 min) respectively. At heights of 97 km [OI (^{1}S)] and 250 km [OI (^{1}D)], these concentric gravity waves are sporadically visible depending on the possible vertical movement of airglow layer height. The dissipated portions of these concentric gravity waves get converted into turbulence at these heights. Using anelastic gravity wave dispersion relation, decreasing horizontal wavelength from the centre of concentric gravity waves is explained. This result is novel in the sense that it disagrees with most of the earlier interpretations of such observations. This work has been done in collaboration with Bilal A. Ganaie, Aashiq H. Bhat, and T. K. Ramkumar.

Effects of calibration uncertainties on the detection and parameter estimation of isotropic gravitational-wave backgrounds

Gravitational-wave backgrounds are expected to arise from the superposition of gravitational wave signals from a large number of unresolved sources and also from the stochastic processes that occurred in the Early universe. So far, we have not detected any gravitational wave background, but with the improvements in the detectors' sensitivities, such detection is expected in the near future. The detection and inferences we draw from the search for a gravitational-wave background will depend on the source model, the type of search pipeline used, and the data generation in the gravitational-wave detectors. In this work, we focus on the effect of the data generation process, specifically the calibration of the detectors' digital output into strain data used by the search pipelines. Using the calibration model of the current LIGO detectors as an example, we show that for power-law source models and calibration uncertainties $\leq$10%, the detection of isotropic gravitational wave background is not significantly affected. We also show that the source parameter estimation and upper limits calculations get biased. For calibration uncertainties of $\leq$ 5%, the biases are not significant ($\leq$ 2%), but

for larger calibration uncertainties, they might become significant, especially when trying to differentiate between different models of isotropic gravitational-wave backgrounds. This work has been done in collaboration with Junaid Yousuf, and Shivaraj Kandhasamy.

Ram Ajor Maurya

Transverse Oscillation of Coronal Loops Induced by Eruptions of Magnetic Flux Tube and Plasmoid

We studied transverse oscillations in hot coronal loops of active region NOAA 12673 located at the west limb. Loop oscillations were associated with a plasmoid ejection from the same location. During the rising phase of the plasmoid, a magnetic flux tube was seen to be rising and bending towards the loop system that erupted before the plasmoid ejection. In addition to the plasmoid ejection, a large coronal mass ejection (CME) and an X8.2 flare were observed in the same active region for several hours (≈ 7 hours). After the plasmoid ejection, a follow-up shock wave from the flare site was triggered by a sudden momentum transfer towards the solar disk. It was found to be propagating across the entire solar disk with an average speed of $\approx 1290\,\mathrm{km\,s^{-1}}$. By analyzing the time sequence of these events, we found that a plasmoid ejection perturbed the loops from their equilibrium and set them in oscillations. We found different oscillations of the fundamental mode in two loops, fast decaying (with a period of 7.93 minutes and an average damping time of $\approx$ 19 minutes) and slow decaying (with a period of 6.31 minutes and an average damping time of $\approx$ 34 minutes). The two different oscillations could be due to their lengths, magnetic fields and plasma densities. Using the methods of coronal seismology, we estimated the average magnetic field in coronal loops to be 29 G and 36 G, which is consistent with the order of the coronal magnetic fields found in other studies. This work has been done in collaboration with Safna Banu K., and Jain Jacob P. T.

Irom A. Meitei

Modified Hawking temperature of Kerr-Newman black hole in Lorentz symmetry violation theory

In this paper, we study the quantum tunneling of scalar particles near the event horizon of Kerr-Newman black hole under Lorentz violation theory. First, the modified Hamilton-Jacobi equation under Lorentz violation theory in curved spacetime is reviewed. The modified Hawking temperatures, heat capacities and entropies of Kerr-Newman black hole in frame dragging coordinates and Eddington coordinate are derived. The modified Hawking temperature, heat capacity and change in Bekenstein-Hawking entropy of Kerr-Newman black hole are found to be modified due to Lorentz violation theory and they depend not only on Lorentz violation parameter λ but also on ether-like vector u^α. This work has been done in collaboration with Y. Priyobarta Singh, T. Ibungochouba Singh and A. Keshwarjit Singh.

Modified entropy of Kerr-de Sitter black hole in Lorentz symmetry violation theory

The quantum tunneling radiation of scalar particles near the event horizon of Kerr-de Sitter black hole is investigated in three systems of coordinates namely naive coordinate system, Paileve coordinate system and Eddington coordinate system using Lorentz violation theory in curved space time. The Klein-Gordon equation of scalar particles is transformed into Hamilton-Jacobi equation by using Lorentz violation theory in curved spacetime. We observe that due to Lorentz violation theory, the expressions of Hawking temperatures, the Bekenstein Hawking entropies and heat capacities near the event horizon of Kerr de Sitter black hole are modified. The Hawking temperatures, entropies and heat capacities increase or decrease depending upon the choices of ether like vectors u^α. This work has been done in collaboration with Y. Onika Laxmi and T. Ibungochouba Singh.

Manesh Michael

Effect of dust size distribution on dust acoustic solitary waves in a six component cometary plasma

The characteristics of dust acoustic (DA) solitary waves in a dusty plasma system composed of positive and negative dust particles whose radii are in a range, together with two components of superthermal electrons with different temperatures and spectral indices and two components of nonthermal ions have been investigated. The Kadomstev?Petviashvili (KP) equation was derived using the reductive perturbation method. The effects of the superthermality of the electrons, nonthermal parameter of the ions and the densities of the dust particles on the amplitude, phase velocity and width of the DA solitary wave have been analyzed. It is observed that for different magnitudes of the power-law index that governs the dust particle distribution and number densities, rarefactive solitary waves are mostly

generated in the plasma system. However, for low values of this index, the rarefactive solitary wave transforms into a compressive one. Further, it is found that the DA solitary waves are significantly influenced by the superthermality of the electrons, nonthermal parameter of the ions, the dust particle densities and their sizes. This work has been done in collaboration with S. Shilpa, and Chandu Venugopal.

Hameeda Mir

Gupta-Feynman based Quantum Theory of Gravity and the Compressed Space

In this work we develop the quantum theory of gravity in the gravitational compressed space. The equivalence of spatial compression to the Lorentz contraction of special relativity, supported by the relative gravitational red-shift using the black hole clock leads to the brane potential and gives the minimum length at which the extra dimensions become dominant, comparable to that of the Schwarzschild radius. For Planck mass the minimum length is almost Planck's length. When doing the quantization of the theory, we find that those responsible for the evolution of time for luminous matter, graviton and for dark matter, the axion, have the property that in compressed gravitational space, naked and dressed propagators are equal and coincide with the corresponding naked propagators. This work has been done in collaboration with M.C.Rocca.

Thermo-statistics of Newtonian Gravity at Short Distances

Classical Newtonian gravitation (CNG) encounters problems at short distances because of the emergence of quantum effects. Experimentally, CNG has been shown to be valid down to 52 micrometers. Here we undertake a classical canonical ensemble treatment of Newtonian gravitation (NG) and discover interesting effects at very short distances. This work has been done in collaboration with A. Plastino, and M.C.Rocca.

Bivudutta Mishra

Dynamical systems analysis in $f(T, \phi)$ gravity

Teleparallel based cosmological models provide a description of gravity in which torsion is the mediator of gravitation. Several extensions have been made within the so-called teleparallel equivalent of general relativity which is equivalent to general relativity at the level of the equations of motion where attempts are made to study the extensions of this form of gravity and to describe more general functions of the torsion scalar T. One of these extensions is $f(T, \phi)$ gravity; T and ϕ respectively denote the torsion scalar and scalar field. In this work, the dynamical system analysis has been performed for this class of theories to obtain the cosmological behaviour of a number of models. Two models are presented here with some functional form of the torsion scalar and the critical points are obtained. For each critical point, the stability behaviour and the corresponding cosmology are shown. Through the graphical representation, the equation of state parameter and the density parameters for matter-dominated, radiation-dominated and dark energy phase are also presented for both the models. This work has been done in collaboration with L.K. Duchaniya, S.A. Kadam, and Jackson Levi Said.

Analyzing the geometrical and dynamical parameters of modified Teleparallel-Gauss-Bonnet model

To recreate the cosmological models, we employed the parametrization approach in modified teleparallel Gauss-Bonnet gravity. It has been interesting to apply the parametrization approach to investigate cosmological models. The real benefit of using this method is that the observational data may be incorporated to examine the cosmological models. Several cosmological parameters were examined, such as the Hubble parameter (H), the deceleration parameter (q), and the equation of state (EoS) parameter (ω). The results obtained are consistent with recent cosmological findings in the conventional scenario. A transition scenario from a decelerating stage to an accelerating stage of cosmic evolution has been observed. The EoS parameter is also in the quintessence phase, which drives the accelerating expansion of the Universe. Also, we look at the violation of strong energy conditions, which has become inevitable in the context of modified gravitational theory. Finally, we have performed the $Om(z)$ diagnostic and also obtained the age of the Universe by using the data from the cosmological observations. This work has been done in collaboration with Santosh V. Lohakare, S.K. Maurya, and Ksh. Newton Singh.

Sajahan Molla

Possible Existence of Dark-Matter-Admixed Pulsar in the Disk Region of the Milky Way Galaxy

In our previous study, we have discussed the possible existence of the dark-matter-admixed pulsars, located in dwarf as well as in massive spiral galaxies (based on Singular Isothermal Sphere dark-matter density profile) and in the Milky Way galaxy (based on Universal Rotational Curve dark-matter density profile). In this article, we use the Navarro-Frenk-White (NFW) dark-matter density profile to get analogous results for the pulsars in the disk region of the MilkyWay galaxy. These findings may be treated as valuable complements to the previous findings. We conclude from our findings that there is a unique possibility of the presence of dark-matter-admixed pulsars in all the regions of the galaxies. This study has been done in collaboration with Nilofar Rahman, Masum Murshid and Mehedi Kalam.

Aditya Sow Mondal

Evidence of hard power-law spectral cutoff and disc reflection features from the X-ray transient XTE J1739-285

We report on the nearly simultaneous *NICR* and *NuSTAR* observations of the known X-ray transient XTE J1739-285. These observations provide the first sensitive hard X-ray spectrum of this neutron star X-ray transient. The source was observed on 19 February 2020 in the hard spectral state with a luminosity of 0.007 of the Eddington limit. The broadband $1-70$ KeV *NICR* and *NuSTAR* observation clearly detects a cutoff of the hard spectral component around 34-40 KeV when the continuum is fitted by a soft thermal component and a hard power-law component. This feature has been detected for the first time in this source. Moreover, the spectrum shows evidence for disc reflection – a relativistically broadened Fe K α line around 5-8 KeV and a Compton hump in the 10-20 KeV energy band. The accretion disc reflection features have not been identified before from this source. Through accretion disc reflection modeling, we constrain the radius of the inner disc to be $R_{in} = 3.1^{+1.8}_{-0.5}; R_{ISCO}$ for the first time. In addition, we find a low inclination, i$\sim 33^0$. Assuming the magnetosphere is responsible for such truncation of the inner accretion disc above the stellar surface, we establish an upper limit of 6.2×10^8 G on the magnetic field at the poles. This work has been done in collaboration with B. Raychaudhuri, G. C. Dewangan and Aru Beri.

Spacelike trajectories in BTZ spacetime and comparison with timelike and lightlike trajectories

Spacelike trajectories or the motion of tachyons in (2+1) dimensional BTZ spacetime is discussed. Study of effective potential is also done and it is shown that unlike tardyons or photons the effective potential does not have any local or global extremum. It rather possesses an infliction point which depends on, along with the black hole parameters, the integrals of motion. Tachyons are, however, found to be sensitive to, like photons and tardyons, the usual frame dragging effect due to the rotational feature of BTZ spacetime and thus pure radial motion cannot persist. It is further found that there exists no circular orbits except at the horizon. That the timelike object shows the same behaviour in this case is a remarkable feature of $(2+1)$ dimensional gravity. Moreover, a trapping of tachyon at the horizon is also indicated. Comparisons with the timelike and the lightlike trajectories and the effective potentials of the three types of particles have been done. This work has been done in collaboration with Soumya Kanti Roy, and B. Raychaudhuri.

Mahadevappa Naganathappa

Theoretical study of infrared and ultraviolet spectra of 14 isomers of C_{24} and comparison with astronomical observations

The present paper discusses the infrared features of C_{24} based on the density functional theory calculation and suggests some of the features observed in celestial objects may be attributed to C24. We also calculate the electronic absorption spectra of the C_{24} isomers to compare with the bump feature at 217 nm in the interstellar extinction curve. The C_{24} isomers are of four groups viz. cage, planar, bowl, and ring forms, and the present study considers their neutral and charged states. The structural parameters are reported for the ?rst time. The planar structure is the most stable and the ring structure has a signi?cant dipole moment observed. We extract theoretical infrared spectra of fourteen isomers in their neutral and charged states at the B3LYP/6–311++G$*$ $*$ level of theory. The time-dependent density functional theory approach is used to calculate the electronic transitions, the absorbance, and the Highest Occupied Molecular Orbitals (HOMO) to Lowest Unoccupied Molecular Orbitals (LUMO) gaps of the 14 C_{24} isomers in their

neutral and charged states. Upon ionization, signi?cant changes are observed in the infrared and electronic absorption spectra, and the structural parameters. Average theoretical spectra of the cage, planar, bowl, and ring of the C_{24} isomer show the features at 6.2, 7.65, 8.65, 11.3, 12.8, and 35.6 μm, which match with the features in the observed spectra of the re?ection nebulae, NGC 2023 and NGC 7023. A sign of a bump in the ultraviolet at around 218 nm is observed in the electronic absorption spectra. This work has been done in collaboration with Venkata Lakshmi Karri, Sumalya Kaluva, Ajay Chaudhari, and Takashi Onaka.

Many-body analysis and spectroscopic characterization of diazene oligomers: A theoretical study

The present study reports the many-body analysis and spectroscopic characterization of linear and cyclic diazene oligomers in gas and water solvent states. The oligomers of diazene from monomer to pentamer have been considered for the study. The spectroscopic studies such as geometrical parameters, infrared spectra, electronic absorption spectra, and natural transition orbitals (NTOs) were reported. Many-body analysis techniques have been implemented to study the interactions among the diazene oligomers. These calculations have been performed using exchange and correlation functional (B3LYP) and 6?311++G (d,p) basis set. The geometrical parameters and infrared modes of monomer diazene in the gas state are well-matched with the available experimental determinations at this level of theory. A significant change in vibrational modes of linear and cyclic diazene oligomers has been observed in the gas phase-to-water solvent state. The time-dependent density functional theory (TD-DFT) has been used to calculate the electronic absorption spectra of diazene oligomers. The Wavelength of electronic transitions, oscillator strength, and HOMO to LUMO gap has been reported. Many-body analysis shows that two-, three-, four-, and five-body energies have a remarkable contribution to the binding energy in addition to relaxation energies. All these calculations have been performed using Gaussian 16 program package. This study has been done in collaboration with Sumalya Kaluva, Venkata Lakshmi Karri, and Bhagwat Kharat.

Hemwati Nandan

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 Einstein's 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 study has been done in collaboration with Shobhit Giri1, Lokesh Kumar Joshi , and Sunil D. Maharaj.

Chaotic motion and Periastron precession of spinning test particles moving in the vicinage of a Schwarzschild black hole surrounded by a quintessence matter field

In the present work, our main objective is to investigate the orbits of spinning test particles around a Schwarzschild black hole under the influence of a quintessence matter field (SQBH). We begin with the dynamics of the spinning test particles around SQBH which is governed by the Mathisson-Papapetrou-Dixon (MPD) equations under the pole-dipole approximation, where the gravitational field and the higher multipoles of the particle are neglected. Depending on the types of saddle points, the effective potential are classified and the possibility of chaotic orbits is discussed. The innermost stable circular orbits (ISCOs) of the spinning particle around SQBH are addressed, as are the effects of the parameters S (particles' spin) and ϵ (equation of state parameter). Later, Periastron precession is investigated up to the first-order spin correction for a spinning particle moving in nearly circular orbits around SQBH. It is noted that the addition of particle's spin revamps the results obtained for the non-spinning particles and also articulates the some interesting observational properties of the SQBH. Additionally, we discuss the ramifications of employing first-order spin corrections for analysing ISCOs, as well as compare our

results to the Schwarzschild BH to ensure that they are consistent in the limit when equation of state parameter $\epsilon = -1/3$ and normalization factor $\alpha \to 0$. This work has been done in collaboration with Shobhit Giri1 , Pankaj Sheoran, and Sanjar Shaymatov.

P. R Prince

Sunspot-Cycle Evolution of Major Periodicities of Solar Activity

Solar activity is generally periodic in nature, having a main periodicity of 11 years, known as the solar cycle. Sunspots are one of the visible indicators of this cycle, and its different characteristics have been known for many years. Due to the presence of irregularities - long and short-term trends, stochasticity, etc. - it is difficult to predict solar activity. In sunspot cycles, amplitude and duration are highly varying parameters, making their prediction chal- lenging. In this study, wavelet analysis of sunspot numbers for the period 1819 -2019 is car- ried out to find the long- and short-term periodic variations in different cycles and changes in cycle duration. The assumptions of the flux-transport dynamo model of the sunspot cycle are used as the basis for the interpretation of the results. The results bring out 10.1-, 10.8-, and 11.6-year periods as the basic periodicities of the sunspot cycle and the ones having the highest strength in a sunspot cycle. Further, their amplitudes have been found to depend on whether the solar cycle belongs to a grand episode or a regular one. Solar-cycle dura- tion is mainly determined by the length of the basic periodicities of the sunspot cycle, and major irregularities in the duration of Solar Cycles 9, 20, and 23 are caused by modulation of periodic trends. Since all the types of variations shown by the duration of the sunspot cycle appear related to the meridional-flow circulation, the results of the study explain the characteristic changes of this circulation postulated by the flux-transport dynamo model. This work has been done in collaboration with G.L. Jayalekshmi, and Tarun Kumar Pant.

Shibesh Kumar Jas Pacif

A new parametrization of Hubble parameter in $f(Q)$ gravity

In this paper, we examine the accelerated expansion of the Universe at late-time in the framework of $f(Q)$ gravity theory in which the non-metricity scalar Q describes the gravitational interaction. To this, we propose a new parametrization of the Hubble parameter using a model-independent way and apply it to the Friedmann equations in the FLRW Universe. Then we estimate the best fit values of the model parameters by using the combined datasets of updated $H(z)$ consisting of 57 points, the Pantheon consisting of 1048 points, and BAO datasets consisting of six points with the Markov Chain Monte Carlo (MCMC) method. The evolution of deceleration parameter indicates a transition from the deceleration to the acceleration phase of the Universe. In addition, we investigate the behavior of statefinder analysis and Om diagnostic parameter, Further, to discuss other cosmological parameters, we consider a $f(Q)$ model, specifically, $f(Q) = Q + mQ^n$, where m and n are free parameters. Finally, we find that the model supports the present accelerating Universe, and the EoS parameter behaves like the quintessence model. This work has been done in collaboration with M. Koussour , M. Bennai , and P.K. Sahoo.

Cosmological implications of an interacting model of dark matter & dark energy

In this paper, we have studied an interacting dark energy model. We have assumed the gravitational interaction between the matter fields i.e. between barotropic fluid and the dark energy. The dark energy evolution within the framework of spatially homogeneous and isotropic Friedmann-Robertson-Walker space-time. Therefore, we examine the cosmic evolution from the perspective of interacting scenario by selecting a suitable ansatz for the scale factor resulting from a parametrization of Hubble parameter. The evolution of the cosmological parameters are discussed in some details in the considered interacting scenario by calculating parameters and quantities such as deceleration parameter, energy density, pressure, equation of state (EoS) etc. Also, we have performed some cosmological tests and analysis in support of our obtained interacting model. Finally, we reconstruct the potential of the scalar field and refute the refined swampland conjecture using the equation of state of dark energy and the relationship between energy density and pressure with the scalar field and potential, and then thoroughly describe the findings. This work has been done in collaboration with Keshav Ram Mishra,Rajesh Kumar, and Kazuharu Bamba.

Biswajit Pandey

Tomography of stellar halos: what does anisotropy in a stellar halo tell us?

The stellar halo of the Milky Way is known to have a highly lumpy structure due to the presence of tidal debris and streams accreted from the satellite galaxies. The abundance and distribution of these substructures can provide a wealth of information on the assembly history of the Milky Way. We use some information-theoretic measures to study the anisotropy in a set of Milky Way-sized stellar halos from the Bullock & Johnston suite of simulations that uses a hybrid approach coupling semi-analytic and N-body techniques. Our analysis shows that the whole-sky anisotropy in each stellar halo increases with the distance from its centre and eventually plateaus out beyond a certain radius. All the stellar halos have a very smooth structure within a radius of $\sim$ 50 kpc and a highly anisotropic structure in the outskirts. At a given radius, the anisotropies at a fixed polar or azimuthal angle have two distinct components: (i) an approximately isotropic component and (ii) a component with large density fluctuations on small spatial scales. We remove the contributions of the substructures and any non-spherical shape of the halo by randomizing the polar and azimuthal coordinates of the stellar particles while keeping their radial distances fixed. We observe that the fluctuating part of the anisotropy is completely eliminated, and the approximately uniform component of the anisotropy is significantly reduced after the sphericalization. A comparison between the original halos and their sphericalized versions reveals that the approximately uniform part of the anisotropy originates from the discreteness noise and the non-spherical shape of the halo whereas the substructures contribute to the fluctuating part. We show that such distinction between the anisotropies has the potential to constrain the shape of the stellar halo and its substructures.

The maximum extent of the filaments and sheets in the cosmic web: an analysis of the SDSS DR17

Filaments and sheets are striking visual patterns in cosmic web. The maximum extent of these large-scale structures are difficult to determine due to their structural variety and complexity. We construct a volume-limited sample of galaxies in a cubic region from the SDSS, divide it into smaller subcubes and shuffle them around. We quantify the average filamentarity and planarity in the three-dimensional galaxy distribution as a function of the density threshold and compare them with those from the shuffled realizations of the original data. The analysis is repeated for different shuffling lengths by varying the size of the subcubes. The average filamentarity and planarity in the shuffled data show a significant reduction when the shuffling scales are smaller than the maximum size of the genuine filaments and sheets. We observe a statistically significant reduction in these statistical measures even at a shuffling scale of $\sim$ 130 Mpc, indicating that the filaments and sheets in three dimensions can extend up to this length scale. They may extend to somewhat larger length scales that are missed by our analysis due to the limited size of the SDSS data cube. We expect to determine these length scales by applying this method to deeper and larger surveys in future. This work has been done in collaboration with Prakash Sarkar, and Suman Sarkar.

Amit Pathak

Rotational spectra of interstellar N- and CN-PAHs: pyrene and coronene

The detection of benzonitrile (C_6H_5CN), 1- and 2-cyano-naphthalene ($C_{10}H_7CN$) in the cold, dark molecular cloud TMC-1 at centimetre (cm) wavelengths has opened up prospects for the detection of other N- and CN-containing polycyclic aromatic hydrocarbons (PAHs). In this light, the pure rotational spectra of N-pyrene ($C_{15}H_9N$), CN-pyrene ($C_{15}H_9CN$), N-coronene ($C_{23}H_{11}N$), and CN-coronene ($C_{23}H_{11}CN$) are reported here for the first time. The B3LYP/6-311 + G (d, p) level of theory, in the density functional theory (DFT) calculations, achieves the best performance for calculating the spectroscopic parameters and simulating the rotational spectra. The large permanent dipole moment of CN-PAHs makes them the most suitable PAH species for detection in the interstellar medium. Additionally, pyrenes smaller partition function makes CN-pyrene a prime candidate to be discovered in cold, dark molecular clouds such as the TMC-1. The present work sets a benchmark for theoretical rotational spectra of N- and CN-containing PAHs and may act as a guide for laboratory experiments and observational searches. This work has been done in collaboration with A. Vats.

Time dependent density functional study of nitrogen-substituted polycyclic aromatic hydrocarbons and diffuse interstellar bands

This work reports theoretical calculations of electronic transitions in nitrogen-substituted polycyclic aromatic hydrocarbon neutrals and cations, using time-dependent density functional theory. The results obtained are compared with the diffuse interstellar bands, a broad group of absorption bands that can be seen mostly in near-ultraviolet and near-infrared wavelengths of the spectrum. It is observed that with nitrogen substituted at the periphery (exoskeletal), these nitrogen substituted polycyclic aromatic hydrocarbon neutrals and their cation counterparts, similar to their corresponding parent polycyclic aromatic hydrocarbons, absorb in the near-ultraviolet and near-infrared wavelengths, respectively. The analogy then follows a change with nitrogen entering into the structure (endoskeletal) and the nitrogen-substituted polycyclic aromatic hydrocarbon neutrals and cations, unlike their corresponding pure polycyclic aromatic hydrocarbon family, fall in the near-infrared and visible spectral regions, respectively. Based on these and other astrophysical implications, it is concluded that nitrogen-substituted polycyclic aromatic hydrocarbons represent a powerful class of prospective carriers of diffuse interstellar bands. This work has been done in collaboration with N. Shukla, A. Vats, and G.A. Ahmed.

Bikash C. Paul

Anisotropic Universe with Barrow Holographic Dark Energy

Anisotropic Bianchi type-I universe is studied in the presence of Barrow holographic dark energy and matter. The proposed holographic principle by Barrow where the standard Bekenstein?Hawking entropy is a special case employed to describe dark energy (DE) in the universe. The evolution of matter density and DE density is studied. The equation of state parameter of DE is found to behave as quintessence or phantom type at the present epoch depending on the new exponent of Barrow?s entropy and anisotropy in the universe. We found that an anisotropic universe with higher anisotropy transits to a late accelerating phase before a universe transits with lower anisotropy. This work has been done in collaboration with B. C. Roy, and A. Saha.

Investigation of Late Universe in the presence of Interaction

Cosmological models are obtained in modified theories of gravity with coupled Gauss-Bonnet (GB) terms in the gravitational action. Two different modified theories namely, (i) $f(R) = R + \gamma R^2 - \lambda \left(\frac{R}{3m_s^2}\right)^{\delta}$ where γ, λ and δ are arbitrary constants and (ii) $f(R) = R$ are considered with GB terms coupled with a free scalar field in the presence of interacting fluid in the first case and coupled with scalar field in a self-interacting potential to compare the dynamical role of GB terms in observed universe. The evolutionary scenario of the universe is obtained adopting a numerical technique as the field equations are highly non-linear. Defining a new density parameter Ω_H a ratio of the dark energy density to the present energy density of the non-relativistic matter, we explore late accelerating universe in the presence of linear interaction among the fluids. The state finder parameters, Ω_H, deceleration parameter (q), jerk parameter (j) are plotted with redshift parameter (z). A non-singular universe emerged with oscillating cosmological parameters for a given strength of interactions in Model-I. The gravitational coupling constant λ plays an important role. The Lagrangian for $f(R)$ is found to dominate over the GB terms when oscillating phase of dark energy arises. Such oscillation of the cosmological parameters are absent as the universe evolve in Model-II. In the presence of interaction the energy from radiation sector of matter cannot flow to the other two sectors of fluid dark energy and dark matter. The strengths of interaction of the fluids are determined for a stable universe assuming the primordial gravitational wave speed equal to unity. (B. C. Paul, A. Chanda, A. Beesham, S. D. Maharaj, CQG, 2022) Subequently the modified theories of gravity are explored with exponential interaction and more information about the interaction originated in the universe initiated the transition to the late accelerating phase This Work has been done in collaboration with A. Chanda, A. Halder,and A. S. Majumdar.

Surajit Paul

Deciphering the ultra-steep-spectrum diffuse radio sources discovered in the cool-core cluster Abell 980

Clusters of galaxies are excellent laboratories for studying recurring nuclear activity in galactic nuclei since their hot gaseous medium can vastly prolong the detectability of their radio lobes via better confinement.

We report here a multi-band study of the sparsely studied galaxy cluster Abell 980, based on our analysis of *Chandra* X-ray data and GMRT (150 and 325 MHz) and EVLA (1.5 GHz) radio archival data, revealing an unusually rich phenomenology. It is shown to be a quasi-relaxed cluster with a cool core ($T \sim 4.2$ keV) surrounded by a hot and extensive intracluster medium (ICM) at $T \sim 6.8$ keV. The radio emission shows a rich diversity, having (i) two large diffuse sources of ultra-steep spectrum (USS) extending to opposite extremities of the ICM, each associated with an X-ray brightness discontinuity (cold front); (ii) a bright radio-double of size $\sim$ 55 kpc coinciding with the central BCG; and (iii) a diffuse radio source, likely a mini-halo of size $\sim$ 110 kpc around the BCG which possesses a huge ellipsoidal stellar halo of extent $\sim$ 80 kpc. The association of cold fronts with two highly aged ($\sim$ 260 Myr) USS sources in a cool-core cluster makes it a very rare system. These USS sources are probably radio lobes from a previous episode of jet activity in the BCG, driven buoyantly towards the outskirts of the X-ray halo, thereby creating the cold fronts. A deeper radio image of this cluster may provide a rare opportunity to verify the recently proposed alternative model which explains radio mini-haloes as the aggregate radio emission from Type Ia supernova remnant occurring in the giant stellar halo extended across the cluster core. This work has been done in collaboration with S. Salunkhe, G. Krishna, S. Sonkamble, and S Bhagat.

The radio source in Abell 980: A Detached-Double-Double Radio Galaxy?

It is argued that the new morphological and spectral information gleaned from the recently published LoFAR Two meter Sky Survey data release 2 (LoTSS-2 at 144 MHz) observations of the cluster Abell 980 (A980), in combination with its existing GMRT and VLA observations at higher frequencies, provide the much-needed evidence to strengthen the proposal that the cluster's radio emission comes mainly from two double radio sources, both produced by the brightest cluster galaxy (BCG) in two major episodes of jet activity. The two radio lobes left from the previous activity have become diffuse and developed an ultra-steep radio spectrum while rising buoyantly through the confining hot intra-cluster medium (ICM) and, concomitantly, the host galaxy has drifted to the cluster centre and entered a new active phase manifested by a coinciding younger double radio source. The new observational results and arguments presented here bolster the case that the old and young double radio sources in A980 conjointly represent a 'double-double' radio galaxy whose two lobe-pairs have lost colinearity due to the (lateral) drift of their parent galaxy, making this system by far the most plausible case of a 'Detached-Double-Double Radio Galaxy' (dDDRG). This work has been done in collaboration with Gopal-Krishna, S. Salunkhe, and S. Sonkamble.

Anirudh Pradhan

The Mass-Radius relation for quark stars in energy-momentum squared gravity

We study the structure of quark stars (QSs) adopting homogeneously confined matter inside the star with a 3-flavor neutral charge and a fixed strange quark mass m_s. We explore the internal structure, and the physical properties of specific classes of QSs in the recently proposed energy-momentum squared gravity (EMSG). Also, we obtain the mass-radius ($M-R$) and mass-central energy density ($M-\rho_c$) relations for QS using the QCD motivated EoS. The maximum mass for QSs in EMSG is investigated depending on the presence and absence of the free parameter α. Furthermore, the stability of stars is determined by the condition $\frac{dM}{d\rho_c} > 0$. We observe that consideration of the EMSG has specific contributions to the structure of QSs. This study has been done in collaboration with T. Tangphati, I. Karar, and A. Banerjee.

Cosmic acceleration and ekpyrotic bounce with Chameleon field

In this paper, we explore the homogeneous and isotropic flat Friedmann-Robertson- Walker (FRW) model in Chameleon cosmology. By considering a non-minimal coupling between the scalar field and matter, we present a non-singular bouncing cosmological scenario of the universe. The universe initially exhibits the ekpyrotic phase during the contracting era, undergoes a non-singular bounce, and then in expanding era, it smoothly transits to the decelerating era having matter and radiation-dominated phases. Further, this decelerating era is smoothly connected to the late-time dark energy-dominated era of the present epoch. We use numerical solution techniques to solve non-minimally coupled gravity equations for understanding the evolution of scalar field along with other quantities like effective potential in the model. The model thus unifies an ekpyrotic, nonsingular,

asymmetric bounce with the dark energy era of the present epoch. We study the evolution of bouncing model and confront the model with observational results on the equation of state parameter by constraining the model parameters. This work has been done in collaboration with Ashutosh Singh.

Ram Prasad Prajapati

Dissipation of hydromagnetic waves in the viscous polytropic zone of the solar wind including FLR corrections, ohmic diffusion, and the Hall effect

In the polytropic zone of the solar wind, we have used the generalized polytrope pressure laws to investigate the dissipation of hydromagnetic waves and pressure-anisotropy-driven fluid instabilities in magnetized viscous plasmas, including finite Larmor radius (FLR) corrections and non-ideal magnetohydrodynamic (MHD) effects. The modified dispersion properties have been analysed in the MHD and Chew?Goldberger?Low (CGL) limits for typical conditions of the solar wind and corona. The theoretical results are found to be in good agreement with the observational data, which shows that the MHD and CGL waves are dissipated due to viscous and ohmic diffusion. The FLR and Hall parameters show destabilizing and stabilizing influences, respectively, for the strong magnetic fields in the solar corona, and reversed effects in the case of weak magnetic fields in the solar wind. In the solar corona, the CGL wave dissipation achieves the required damping rate in the minimum time than the dissipation of the MHD waves. The damping time is mainly associated with the considered parameters and was found to be larger for the MHD wave dissipation than the CGL wave dissipation. The theoretical results successfully demonstrate the role of the considered parameters on the reverse and forward shock waves and instabilities as observed in the solar wind parameters versus heliolatitude graph using Ulysses observations for r = 5.41 au. The results are helpful to explore the possibilities of MHD waves and pressure-anisotropy-driven fluid instabilities in the polytropic zone of the solar wind that will probably be observed by the Parker Solar Probe (PSP) mission. This work has been done in collaboration with Ephrem Tesfaye Desta, Mei-Ching Fok, and Tigistu Haile Eritro.

Effects of heat-flux vector and Braginskii viscosity on wave dissipation and instabilities in rotating gravitating anisotropic plasma

The pressure anisotropy-driven magnetohydrodynamic (MHD) waves and instabilities are the significant sources of energy transfer in astrophysical outflows, such as solar wind, spiral arms of galaxies and accretion disks. The heat-flux corrections, rotation and anisotropic viscosity play an unavoidable role in the wave dissipation and instabilities in such systems. In this work, we have investigated the effects of heat-flux vector and Braginskii viscosity tensor on the low-frequency hydromagnetic Chew-Goldberger-Low (CGL) waves, firehose instability and gravitational instability in uniformly rotating, strongly magnetized and anisotropic heat-conducting plasmas. The Braginskii viscosity tensor is considered in the CGL fluid equations, including heat-flux corrections and uniform rotation, keeping in mind the actual physical conditions of spiral arms of galaxies and solar coronal heating. The linear dispersion properties of gravitational instability, firehose instability, slow and fast CGL wave dissipation have been analyzed in various parametric limits. The dynamical stability of the system is discussed using the Routh?Hurwitz criterion. It is found that in the transverse propagation, the growth rate of the gravitational instability is decreased due to the presence of viscosity, and it remains unaffected due to the heat-flux corrections. In the parallel propagation, the effects of viscosity and heat-flux parameters are found to decrease the threshold wavenumber and stabilize the growth rate of gravitational instability. The upper and lower bounds of wavenumbers that determine the system?s stability, instability and overstability are decreased due to the viscosity and rotation parameters. The numerical calculations of various parameters show that gravitational instability plays a vital role in the spiral arms of the galaxies. The present results have been applied to understand the influence of heat-flux vector, rotation and viscosity on the slow and fast magnetosonic modes in the solar coronal heating mechanism. This work has been done in collaboration with Ephrem Tesfaye Desta, and Tigistu Haile Eritro.

Farook Rahaman

Physical implications of pure Lovelock geometry on stellar structure

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 Ksh. Newton Singh, Megandhren Govender, Sudan Hansraj.

Galactic Wormhole under Lovelock Gravity

We explore wormhole geometry in spiral galaxies under the third order Lovelock gravity. Using the cubic spline interpolation technique, we find the rotational velocity of test particles in the halo region of our spiral galaxy from observed values of radial distances and rotational velocities. Taking this value of the rotational velocity, we are able to show that it is possible to present a mathematical model regarding viable existence of wormholes in the galactic halo region of the Milky Way under the Lovelock gravity. A very important result that we obtain from the present investigation is that galactic wormhole in the halo region can exist with normal matter as well as exotic matter. This work has been done in collaboration with Koushik Chakraborty, Saibal Ray, Banashree Sen, and Debabrata Deb.

Rakhi R.

UVIT view of NGC 5291: Ongoing star formation in tidal dwarf galaxies at ∼ 0.35 kpc resolution

NGC 5291, an early-type galaxy surrounded by a giant HI ring, is believed to be formed from collision with another galaxy. Several star forming complexes and tidal dwarf galaxies are distributed along the collisional ring which are sites of star formation in environments where extreme dynamical effects are involved. Dynamical effects can affect the star formation properties and the spatial distribution of star forming complexes along the tidal features. To study and quantify the star formation activity in the main body and in the ring structure of the NGC 5291 system, we use high spatial resolution FUV and NUV imaging observations from the Ultraviolet Imaging Telescope onboard AstroSat. A total of 57 star-forming knots are identified to be part of this interacting system out of which 12 are new detections (star forming complexes that lie inside the HI contour) compared to the previous measurements from lower resolution UV imaging. We estimate the attenuation in UV for each of the resolved star-forming knots using the UV spectral slope β, derived from the $FUV - NUV$ colour. Using the extinction corrected UV fluxes, we derive the star formation rate of the resolved star forming complexes. The extinction corrected total star formation rate of this system is estimated as 1.75 $\pm$ 0.04 $M_{\odot}/yr$. The comparison with dwarf galaxy populations (BCD, Sm and dIm galaxies) in the nearby Universe shows that many of the knots in the NGC 5291 system have SFR values comparable to the SFR of BCD galaxies. This work has been done in collaboration with Geethika Santhosh, Prajwel Joseph, Koshy George, Smitha Subramanian, et al.

Chayan Ranjit

Exact solution to the geodesic equations in spherically symmetric space-time

The strength of a singularity in spherical symmetry can be described by covariant equations. This was generated by Nolan [Phys. Rev. 60, 024014 (1999)] and some models have been examined him also. It draws a distinction between singularities, i.e. which are central and which are not. Nolan derived the necessary conditions [Phys. Rev. D 62, 044015 (2000)] for the singularity to be gravitationally weak. From these conditions certain conclusions may be drawn about the

nature of the singularity without having to integrate the geodesic equations. In the present letter, the equations for the geodesic in spherically symmetric space-time obtained by Nolan are completely solved. This will lead to a better understanding of the physical situation regarding singularity. This work has been done in collaboration with Haru Chand Dhara, Kamal Kumar Ghosh, Saibal Ray, and Moumita Indra.

Shantanu Rastogi

Study of vibrational spectra of polycyclic aromatic hydrocarbons with phenyl side group

Computational study of polycyclic aromatic hydrocarbons (PAHs) with phenyl side group substituted at different positions is reported. The infrared spectral variations due to the position of phenyl substitution, ionization state and the size of the molecules are discussed and possible contribution of phenyl-PAHs to the mid-infrared emission features from astrophysical objects is analyzed. Structurally phenyl group substitution at 2^{nd} position gives more stable species compared to substitution at other positions. Phenyl-PAHs exhibit new aromatic bands near 695 and 741 cm^{-1} (14.4 and 13.5 μm), due to contribution from quintet C-H wag, that compare well with minor features at 14.2 and 13.5 μm observed in several astrophysical objects. Just as in plain PAHs, the C-C stretch vibrational modes ($\sim$1600 cm^{-1}) have negligible intensity in neutrals, but the cations of all phenyl-PAHs exhibit significantly strong phenyl group C-C stretch peak close to class B type 6.2 μm astrophysical band. In 2-phenylpyrene, it is the neutral molecule that exhibits this strong feature in the 6.2 μm range along with other features that match with sub-features at 6.66 and 6.9 μm, observed in astronomical spectra of some late type objects. The substitution of phenyl side group at solo position shifts the C-C stretch mode of parent PAH close to the 6.2 μm AIB region. The results indicate possibility of phenyl-PAHs in space and the bottom-up formation of medium sized compact PAHs with phenyl side group in carbon rich cool circumstellar shells. Phenyl-PAHs need to be considered in modelling mid-infrared emission spectra of various astrophysical objects. This work has been done in collaboration with A. Maurya, and R. Singh.

Investigation of atmospheric turbulence and scale lengths using radiosonde measurements of GVAX-campaign over central Himalayan region

The atmospheric turbulence characteristics such as energy-dissipation rate (ε), eddy diffusivity (K), and refractive index structure parameter (C_n^2), which are inevitable to understand the vertical mixing and transport of pollutants, momentum, and energy, are least explored over the Himalayan region owing to the unavailability of observations. Here, we investigate the characteristics of turbulence in the troposphere (TS) and lower stratosphere (LS) using Thorpe's method for intense radiosonde measurements made during July 2011 to March 2012, from a central Himalayan site Manora Peak (79.5^{o}E, 29.4^{o}N, and 1936 m AMSL). Findings reveal that the energy dissipation rate (log $\sim$ ε), and eddy diffusivity (log K), are right-skewed with central mean values about -3.90 (-3.30) m^2s^{-3} and -0.19 (-0.24) m^2s^{-1}, in the TS (LS) region. However, C_n^2 follows the right (left) -skewed distribution with the mean value of -16.9 (-19)$m^{-2/3}$, in the TS (LS). The mean values of inner scale 4(l^o) and buoyancy scale (L_B) are 0.051 (0.104) m and 84.62 (8.34) m in the TS (LS). The monthly and seasonal variations of these parameters were also examined and presented. The mean profiles of log $\sim$ ε show the lowest dissipation rate ($-4.5m^2s^{-3}$) during the post-monsoon season and constant dissipation rate ($\sim$ $-4m^2s^{-3}$) below 5 $\sim$ km in winter, however, mixing coefficient log K shows a constant variation $\sim$ $-0.01m^2s^{-1}$ above 8$\sim$km. Larger buoyancy scales (>100 m) are observed in the altitude range of 8–14 km during moist and lighter monsoon circulations. This study extricates the effect of orography-induced local circulations that controls turbulence intensity in the lower troposphere, especially in the weak mean flow conditions. This study essentially provides the quantified vertical distribution of the atmospheric parameters associated with turbulence and to be utilized for understanding the related physical processes. This work has been done in collaboration with A. Rajput, N. Singh, and J. Singh.

Saibal Ray

On the possibility of generalized wormhole formation in the galactic halo due to dark matter using the observational data within the matter coupling gravity formalism

In this article, we find the possibility of generalized wormhole formation in the galactic halo due to dark

matter using the observational data within the matter coupling gravity formalism. Keeping this as a target we specifically employ $f(R,T)$ gravity with (i) a variational approach concerning the metric, and (ii) the anisotropic source of matter. To understand the features of the wormholes we thoroughly have calculated and analyzed the energy conditions under $f(R,T)$ gravity. We discuss the second embedded wormhole solution, known as the generalized Ellis-Bronnikov space-time (ultra-static wormhole model), in terms of the tortoise coordinate. Thereafter we generate and compare different wormhole solutions depending on the parametric values. In the second part of our investigation, we have presented dark matter halos and provided interesting features by considering a couple of profiles. For the dark matter halos models, we particularly use the observational data of the $M87$ galaxy and the Milky Way galaxy. This work has been done in collaboration with G. Mustafa and S. K. Maurya.

IUCAA: Genesis of a Unique Research Centre

The Inter-University Centre for Astronomy and Astrophysics (IUCAA) is the second Inter-University Centre established by the Government of India for promotion of astronomy and astrophysical research. In this article, the historical development as well as the motivation for establishing IUCAA has been discussed which comprises of the period 1988-1993, i.e. the first 5 years. A glimpse of research work in pre- and post-colonial era in India has also been presented to have a holistic view of the genesis. This work has been done in collaboration with Utpal Mukhopadhyay and Samir Dhurde.

Biplab Raychaudhuri

A quest for the origin of the Sagnac effect

In the literature, there is no consensus on the origin of the relativistic Sagnac effect, particularly from the standpoint of the rotating observer. The experiments of Wang et al. (*Phys Lett A* **312**(1-2):7, 2003; *Phys Rev Lett* **93**(14):143901, 2004) has, however, questioned the pivotal role of rotation of the platform in Sagnac effect. Recently, the relative motion between the reflectors which force light to propagate along a closed path and the observer has been ascribed as the cause of the Sagnac effect. Here, we propose a thought experiment on linear Sagnac effect and explore another one proposed earlier to demonstrate that the origin of the Sagnac effect is neither the rotation of frame affecting clock synchronization nor the relative motion between the source and the observer; Sagnac effect originates purely due to asymmetric position of the observer with respect to the light paths. Such a conclusion is validated by analysis of a gedanken Sagnac kind experiment involving rotation. This work has been done in collaboration with Arunava Bhadra, and Souvik Ghose.

Spacelike trajectories in BTZ spacetime and comparison with timelike and lightlike trajectories

Spacelike trajectories or the motions of tachyons in $(2+1)$ dimensional BTZ spacetime are discussed. A study of the effective potential in this case has also been done and it is shown that unlike that for tardyons or photons it does not have any local or global extremum. It rather possesses an inflection point that depends, along with the blackhole parameters, on the integrals of motion. Tachyons are, however, found to be sensitive, like photons and tardyons, to the usual frame dragging effect due to the rotational feature of the BTZ spacetime and thus pure radial motion cannot persist. It is further found that circular orbits exist nowhere except at the horizon. That the timelike object shows the same behaviour in this case is a remarkable feature of $(2+1)$ dimensional gravity. Moreover, the trapping of tachyons at the horizon is also indicated. Comparison of the spacelike trajectories with the timelike and the lightlike trajectories and the corresponding effective potentials have been done analytically and graphically. This work has been done in collaboration with Soumya KantiRoy, and Aditya S. Mondal.

Prabir Rudra

Energy-momentum squared symmetric Teleparallel gravity: $f(Q,T_{\mu\nu}T^{\mu\nu})$ gravity

In this work we propose the $f(Q,T_{\mu\nu}T^{\mu\nu})$ gravity as a further extension of the $f(Q)$ and $f(Q,T)$ gravity theories, where Q is the non-metricity and $T_{\mu\nu}$ is the energy-momentum tensor. The action involves an arbitrary function of the non-metricity Q and $\mathbf{T}^2 = T_{\mu\nu}T^{\mu\nu}$ in the gravity Lagrangian. The field equations for the theory are derived in the metric-affine formalism. The theory involves a non-minimal coupling between the geometric and the matter sectors, and hence the covariant divergence of the energy momentum tensor is non-zero, thus implying the non-conservation of the same. The vacuum solutions of the theory are investigated and it is found that the theory perfectly admits a de-Sitter-like evolution of the universe. The

cosmological equations are derived and it is found that there are two correction terms arising as modification of the gravity. Two specific toy models of the form $Q + \eta\left(\mathbf{T}^2\right)^n$ and $f_0 Q^m \left(\mathbf{T}^2\right)^n$ are explored to gain further insights into the dynamics of the theory. It is seen that the field equations of both the models have terms similar to those arising from the quantum gravity effects and are thus responsible for the avoidance of the singularity. One striking feature of the model is that the non-linear correction terms dominate in the early universe and gradually fade away at later times giving standard FLRW universe. Solutions for the FLRW equations are found wherever possible and the evolution of the scale factor and the matter energy density is plotted. Other cosmological parameters like the equation of state, deceleration parameters and Hubble functions are also studied. Finally the energy conditions are explored in the background of the theory. Using these conditions and some observational data the parameter spaces of the models are considerably constrained. $f(Q, T_{\mu\nu}T^{\mu\nu})$ is a theory that can perfectly explain the cosmological dynamics of both the early and the late universe without resorting to any dark energy.

A Time Dependent Spacetime in $f(R,T)$ Gravity: Gravitational Collapse

In this note a time dependent spacetime is explored in the background of $f(R,T)$ gravity via the gravitational collapse of a massive star. The star is modelled by the Vaidya spacetime which is time dependent in nature. The coupling of matter with curvature is the key feature of $f(R,T)$ theory and here we have investigated its effects on a collapsing scenario. Two different types of models, one involving minimal and the other involving non-minimal coupling between matter and curvature are considered for our study. Power law and exponential functionalities are considered as examples to check the outcome of the gravitational collapse. A detailed analysis on the appearance of horizons in Vaidya spacetime is performed and its astrophysical implications are explored. Our prime objective is to explore the nature of singularities (black hole or naked singularity) that form as an end state of the collapse. Existence of outgoing radial null geodesics from the central singularity was probed and such existence implied the formation of naked singularities thus defying the cosmic censorship hypothesis. The absence of such outgoing null geodesics would imply the formation of an event horizon and the singularity formed becomes a black hole. Conditions under which such possibilities occur are derived for all the models and sub-models. Gravitational strength of the singularity is also investigated and the conditions under which we can get a strong or a weak singularity is derived. The results obtained are very interesting and may be attributed to the coupling between curvature and matter. It is seen that for non-minimal coupling there is a possibility of a globally naked singularity, whereas for a minimal coupling scenario local nakedness is the only option. It is also found that the singularity formed can be sufficiently weak in nature, which is cosmologically desirable.

Sunil Kumar S.

Laser-Induced Fluorescence (LIF) Spectroscopy of Trapped Molecular Ions in the Gas Phase

This review focuses on the laser-induced fluorescence (LIF) spectroscopy of trapped gas-phase molecular ions, a developing field of research. Following a brief description of the theory and experimental approaches employed in general for fluorescence spectroscopy, the review summarizes the current state-of-the-art intrinsic fluorescence measurement techniques employed for gas-phase ions. Whereas the LIF spectroscopy of condensed matter systems is a well-developed area of research, the instrumentation used for such studies is not directly applicable to gas-phase ions. However, some measurement schemes employed in condensed-phase experiments could be highly beneficial for gas-phase investigations. We have included a brief discussion on some of these techniques as well. Quadrupole ion traps are commonly used for spatial confinement of ions in the ion-trap-based LIF. One of the main challenges involved in such experiments is the poor signal-to-noise ratio (SNR) arising due to weak gas-phase fluorescence emission, high background noise, and small solid angle for the fluorescence collection optics. The experimental approaches based on the integrated high-finesse optical cavities employed for the condensed-phase measurements provide a better (typically an order of magnitude more) SNR in the detected fluorescence than the single-pass detection schemes. Another key to improving the SNR is to exploit the maximum solid angle of light collection by choosing high numerical aperture (NA) collection optics. A combination of these two approaches integrated with ion traps could transmogrify this field, allowing one to study even weak fluorescence emission from gas-phase molecular ions. The review concludes by discussing the scope of the advances in the LIF instrumentation

for detailed spectral characterization of fluorophores of weak gas-phase fluorescence emission, considering fluorescein as one example. This work has been done in collaboration with Hemanth Dinesan.

Sanjay K. Sahay

Deep Reinforcement Learning in the Advanced Cybersecurity Threat Detection and Protection

The cybersecurity threat landscape has lately become overly complex. Threat actors leverage weaknesses in the network and endpoint security in a very coordinated manner to perpetuate sophisticated attacks that could bring down the entire network and many critical hosts in the network. To defend against such attacks, cybersecurity solutions are upgrading from the traditional to advanced deep and machine learning defense mechanisms for threat detection and protection. The application of these techniques has been reviewed well in the scientific literature. Deep Reinforcement Learning has shown great promise in developing AI solutions for areas that had earlier required advanced human cognizance. Different techniques and algorithms under deep reinforcement learning have shown great promise in applications ranging from games to industrial processes, where it is claimed to augment systems with general AI capabilities. These algorithms have recently also been used in cybersecurity, especially in threat detection and protection, where these are showing state-of-the-art results. Unlike supervised machine learning and deep learning, deep reinforcement learning is used in more diverse ways and is empowering many innovative applications in the threat defense landscape. However, there does not exist any comprehensive review of deep reinforcement learning applications in advanced cybersecurity threat detection and protection. Therefore, in this paper, we intend to fill this gap and provide a comprehensive review of the different applications of deep reinforcement learning in this field This work has been done in collaboration with Hemant Rathore, and Mohit Sewak.

SAMPARK: Secure and Lightweight Communication Protocols for Smart Parking Management

Many vehicles on the road create significant problems, like parking, traffic congestion, fuel/energy consumption, and so on. Specifically, finding an appropriate parking spot is challenging for vehicle users while moving. Renting private parking spots is worthwhile using information and communications technology to solve parking challenges and offers mutual benefits to vehicle users and parking spot owners. However, security and privacy are prime concerns, as unknown vehicle users use private parking spots. The existing parking schemes are vulnerable to important security and privacy attributes and also inefficient due to high computational costs. We propose secure and lightweight communication protocols for smart parking management (named as SAMPARK) using lightweight cryptographic primitives, (i) to send available parking information and (ii) to reserve a parking spot ahead of time. Security proofs are discussed based on the random oracle model to confirm the security robustness of SAMPARK, considering vital vehicular communication attacks for security analysis. The test-bed results (on Raspberry Pi 3B+) show that the SAMPARK is relatively efficient in computation time, storage cost, and communication overhead. This work has been done in collaboration with Trupil Limbasiya, and Debasis Das.

Pradyumn Kumar Sahoo

Accretion flows around exotic tidal wormholes

This paper investigates the various spherically symmetric wormhole solutions in the presence of tidal forces and applies numerous methods, such as test particle orbital dynamics, ray-tracing and microlensing. We make the theoretical predictions on the test particle orbital motion around the tidal wormholes with the use of normalized by $\mathcal{L}^2$ effective potential. In order to obtain the ray-tracing images (of both geometrically thin and thick accretion disks, relativistic jets), we properly modify the open source `GYOTO` code with python interface. We applied this techniques to probe the accretion flows nearby the Schwarzschild-like and charged Reissner-Nördstrom (RS) wormholes (we assumed both charged RS wormhole and special case with the vanishing electromagnetic charge, namely Damour-Solodukhin (DS) wormhole). It was shown that the photon sphere for Schwarzschild-like wormhole presents for both thin and thick accretion disks and even for the vanishing tidal forces. Moreover, it was observed that $r_{\rm ph} \to \infty$ as $\alpha \to \infty$, which constraints α parameter to be sufficiently small and positive in order to respect the EHT observations. On the other hand, for the case of RS wormhole, photon sphere radius shrinks as $\Lambda \to \infty$, as it was predicted by the effective potential. In addition to the accretion disks, we as well probe the relativistic jets around two

wormhole solutions of our consideration. Finally, with the help of star bulb microlensing, we approximate the radius of the wormhole shadow and as we found out, for Schild WH, $R_{\rm Sh} \approx r_0$ for ZTF and grows linearly with α. On the contrary, shadow radius for charged wormholes slowly decreases with the growing trend of DS parameter Λ. This work has been done in collaboration with O. Sokoliuk, S. Praharaj, and A. Baransky.

Squared torsion $f(T, \mathcal{T})$ gravity and its cosmological implications

We present the coupling of the torsion scalar T and the trace of energy-momentum tensor $\mathcal{T}$, which produces new modified $f(T, \mathcal{T})$ gravity. Moreover, we consider the functional form $f(T, \mathcal{T}) = \alpha\mathcal{T} + \beta T^2$ where α and β are free parameters. As an alternative to a cosmological constant, the $f(T, \mathcal{T})$ theory may offer a theoretical explanation of the late-time acceleration. The recent observational data to the considered model especially the bounds on model parameters is applied in detail. Furthermore, we analyze the cosmological behavior of the deceleration, effective equation of state and total equation of state parameters. However, it is seen that the deceleration parameter depicts the transition from deceleration to acceleration and the effective dark sector shows a quintessence-like evolution. This work has been done in collaboration with Simran Arora, and Aaqid Bhat.

Eeshankur Saikia

Analysing Dominant 13.5-day & 27-day Periods of Solar Terrestrial Interaction: A New Insight into Solar Cycle Activities

Our analysis presents an explanation of Sun-Earth coupling mechanism during declining phase of a Solar cycle, and how the dominant 13.5-day and 27-day periods play roles in the coupling mechanism which led to intense terrestrial magnetic storms during this declining phase compared to the rising phase of a Solar cycle. Moreover, it is observed that while the 27-day period gets strongly modulated in the rising phase, the 13.5-day period modulation is more prominent during the declining phase. It is suggested that out of the 27-day and 13.5-day periods of Sun-Earth interaction, the preferred period of modulation happens to be the one which is more dominant for the less random or quieter system participating in the coupling. It is reported for the first time that the 13.5-day period is more prominent in the Sun-Earth interaction during the declining phase of a Solar cycle, as it is the most dominant period of Earth's magnetic system, which happens to be more persistent as a dynamical system and hence quieter or more receptive than the Sun. This work has been done in collaboration with Rissnalin Syiemlieh, Manashee Adhikary1, and Prasanta K Panigrahi.

A new insight into changes in protoplanetary disk structure caused by change in stellar mass

The observational evidences in recent times of a protoplanetary star-disk system establish that protoplanets carve out specific disk structures, such as, gaps, rings etc. due to their varying orbital motion around a central star. However, the interplay among key physical properties in such a system and the relevant physics are yet to be understood thoroughly. In this work, we simulate such a protoplanetary disk with an embedded planet, which carves out gaps and is allowed to evolve under different Equations of State (E.O.S.) and constituent fluid elements. Previous studies have established a linear dependence of the gap width Δ_{gap} with $K' \sim f(q^2)$, where 'q' is the mass ratio of planet to star. Our study, on the other hand, has found quantitatively a different scaling relationship with changing stellar mass. Induced gap width was found to be wider and the disk to be highly perturbed in stars with low mass. Further analysis suggests that there is a difference in planet induced gap width and disk structures even for the same 'q', while varying individual masses. Variation in the individual mass changes the gravitational force distribution in the disc, leading to disc structure variation, be it in the form of density distribution or the gap width formation, supporting our proposition. This new understanding is significant in designing of numerical experiments, as models used for studying such a system usually undermine the impact of constituent masses on the disk materials, while paying attention only to the mass ratio. This work has been done in collaboration with Dhritimaan Gogoi, Parvej Reja Saleh, and Sankar Moni Borah.

Gauranga C. Samanta

Stability of thin-shell wormhole in 4D EinsteinGaussBonnet gravity

In this paper, we construct a thin-shell wormhole (TSW) in 4D EinsteinGaussBonnet gravity (EGB) and examine the stability condition of the wormhole (WH) by using

the linear and nonlinear models of the exotic ?uid at the throat (α_0). In addition, we have checked the validity of null, weak, and strong energy conditions for the TSWs. The energy conditions are observed to violate the linear model but it satis?es the nonlinear model. Further, 4D EGB wormhole solutions are found to exist for a particular choice of equilibrium radius as well as the equation of state parameter. This work has been done in collaboration with Nisha Godani , and Dharm Veer Singh.

Generic autonomous system approach to interacting dark energy models

We explore an autonomous system analysis of dark energy models with interactions between dark energy and cold dark matter in a general systematic approach to cosmo- logical ?uids. We investigate two types of models such as local and non-local ones. In particular, a local form of interaction is directly proportional to only the energy density, while a non-local interaction is directly proportional to the energy density as well as the Hubble parameter. As a consequence, it is explicitly demonstrated that in both cases there exist the stability points in terms of cosmological parameters. This work aims at obtaining acceleration and stability using interaction models without modifying the matter or geometric component of the Universe. This work has been done in collaboration with Parth Shah, Kazuharu Bamba, and R. Myrzakulov.

Biplob Sarkar

AstroSat observation of rapid type-I thermonuclear burst from low-mass X-ray binary GX 3+1

We report the results of an observation of low-mass X-ray binary GX 3+1 with AstroSat's large area X-ray proportional counter (LAXPC) and soft X-ray telescope (SXT) instruments on-board for the first time. We have detected type-I thermonuclear burst (∼15 s) present in the LAXPC 20 light curve with a double peak feature at higher energies and our study of the hardness-intensity diagram reveals that the source was in a soft banana state. The pre-burst emission could be described well by a thermally Comptonized model component. The burst spectra is modeled adopting a time-resolved spectroscopic method using a single color blackbody model added to the pre-burst model, to monitor the parametric changes as the burst decays. Based on our time-resolved spectroscopy, we claim that the detected burst is a photospheric radius expansion (PRE) burst. During the PRE phase, the blackbody flux is found to be approximately constant at an averaged value of ∼2.56 in 10^{-8} ergs s^{-1} cm^{-2} units. On the basis of literature survey, we infer that AstroSat/LAXPC 20 has detected a burst from GX 3+1 after more than a decade, which is also a PRE one. Utilizing the obtained burst parameters, we provide a new estimation to the source distance, which is ∼9.3 ± 0.4 kpc, calculated for an isotropic burst emission. Finally, we discuss and compare our findings with the published literature reports. This work has been done in collaboration with Ankur Nath, Jayashree Roy, and Ranjeev Misra.

Asoke K. Sen

The space-time line element for static ellipsoidal objects

In this paper, we solved the Einstein's field equation and obtained a line element for static, ellipsoidal objects characterized by the linear eccentricity (η) instead of quadrupole parameter (q). This line element recovers the Schwarzschild line element when η is zero. In addition to that it also reduces to the Schwarzschild line element, if we neglect terms of the order of r^{-2} or higher which are present within the expressions for metric elements for large distances. Furthermore, as the ellipsoidal character of the derived line element is maintained by the linear eccentricity (η), which is an easily measurable parameter, this line element could be more suitable for various analytical as well as observational studies. This work has been done in collaboration with Ranchhaigiri Brahma.

Porous dust particles in astrophysics and their thermal properties

Numerical analogues of non-fractal porous cometary dust particles are generated using a recently introduced model of open-pore solid particles. The refractive index of amorphous silicate is considered and the particle sizes follow a Sekanina-Hanner distribution within the size-range ($0 : 01\mu m - 1\mu m$). Using the Discrete Dipole Approximation (DDA) method, we calculate the thermal re-emission spectrum of a population of porous particles in the spectral region 0.2-39.8 μm and the equilibrium temperature of the particles (when placed at 1 AU distance from Sun). Porosity tends to reduce the temperature of the particles because porous particles radiate heat more effectively than dense particles. A characteristic particle size is determined for which the particle temperature is maximum regardless of the porosity. The temperature of a cloud of

polydisperse particles is more homogeneous for highly porous particles. These results are compared with those generated by Mie theory where the Bruggeman mixing rule is applied (EMT method). When agreement between the DDA and the EMT results is achieved, simple approximations are derived from the EMT to analyze and make clear the various behaviors of the spectral thermal re-emission revealed in the numerical data. In particular, the reason why the emission peak around 10 μm is depressed by porosity and shifted to the smaller wavelength by a steeper particle-size distribution is explained This work has been done in collaboration with Naznin R. Choudhury, R. Botet , and A. Zaman.

Ranjan Sharma

Effects of electric field and anisotropy on the mass-radius relationship of a particular class of compact stars

For a static, spherically symmetric, anisotropic and charged distribution of matter, we present a new class of exact solutions to the Einstein-Maxwell system. By assuming specific forms of the electric field and anisotropy, we transform the master equation of the Einstein-Maxwell system to Bessel and modified Bessel differential equations. The subsequent solutions turn out to be generalizations of the isotropic and uncharged stellar model of Finch and Skea (1989), the isotropic and charged stellar model of Hansraj and Maharaj (2006) and the anisotropic and charged stellar model of Maharaj *et al* (2017). We analyze the physical viability of the solutions and utilize one particular class of solutions to examine the effects of charge and anisotropy on the mass-radius relationship of compact stars. This work has been done in collaboration with K. Komathiraj, and S. Chanda.

Models for charged relativistic spheres via hyper-geometric equations

Exact solutions to Einstein-Maxwell systems play an important role in relativistic astrophysics. In this paper, a new technique to generate exact solutions to the Einstein-Maxwell system is proposed. Corresponding to a spherically symmetric charged fluid sphere, by specifying the electric field and for a particular form of the metric potential g_{rr}, a new solution is obtained in terms of hypergeometric functions. Subsequently, for specific choice of model parameters, many closed-form solutions are developed. In the process, it is possible to regain a number of well-known stellar models which had been developed earlier with or without the presence of charge following the Vaidya and Tikekar ansatz (1982;1990) for compact stars. It is shown that the new class of solutions can be used as viable models for compact stars for a wide range of values of the model parameters. Physical behaviour of the resultant stellar configurations are studied This work has been done in collaboration with S. Thirukkanesh, I. Saparamadu, and S. Bhattacharya.

Umesh Kumar Sharma

Reconstructing Tsallis holographic phantom

The current research considers the Tsallis holographic dark energy (THDE) with the Hubble horizon as an IR cut-off with a non-interacting flat Friedmann-Lemaitre-Robertson-Walker (FLRW) Universe. We investigate the evolutionary behaviour of deceleration and the equation of state parameter for the distinct Tsallis exponent δ and noticed appropriate behaviour in the model. The scalar field of the phantom describes the non-interacting Tsallis holographic dark energy when $\delta > 2$, then we demonstrate the phantomic narration when $\delta > 2$ for the Tsallis holographic dark energy and reconstruct the scalar field potential of the phantom.

Holographic dark energy through Kaniadakis entropy in non flat universe

By extending the standard holographic principle to a cosmological framework and combining the non-flat condition with the Kaniadakis entropy, we construct the non-flat Kaniadakis holographic dark energy model. The model employs Kaniadakis parameter K and a parameter c. Derivation of the differential equation for KHDE density parameter to describe the evolutionary behavior of the universe is obtained. Such a differential equation could explain both the open as well as closed universe models. The classification based on matter and dark energy (DE) dominated regimes show that the KHDE scenario may be used to specify the Universe's thermal history and that a quintom regime can be encountered. For both open and closed, we find the expressions for the deceleration parameter and the equation of state (EoS) parameter. Also, by varying the associated parameters, classical stability of the method is established. On considering the curvature to be positive, the universe favors the quintom behavior for substantially smaller values as opposed to the flat

condition, when only quintessence is attained for such K values. Additionally, we see a similar behavior while considering the negative curvature for such K values. Therefore, adding a little bit of spatial geometry that isn't flat to the KHDE enhances the phenomenology while maintaining K values at lower levels. To validate the model parameters, the most recent 30 $H(z)$ dataset, in the redshift range $0.07 \leq z \leq 1.965$ are utilized. In addition, the distance modulus from the current Union 2.1 data set of type SNIa are employed. This work has been done in collaboration with P. Suresh Kumar, Bramha Dutta Pandey, and Pankaj.

Dharm Veer Singh

Quasinormal modes, shadow and thermodynamics of black holes coupled with nonlinear electrodynamics and cloud of string

We construct an exact black hole solution for the Einstein gravity coupled with the nonlinear electrodynamics (which corresponds to the Maxwell electrodynamics in the weak field limit) in the presence of a cloud of strings as the source. We study the thermodynamical properties of the black hole solutions and derive the corrected first-law of thermodynamics. The presence of a cloud of strings does not affect the stability of the present black hole. However, a second-order phase transition exists for this system at a critical horizon radius. Furthermore, we study the quasinormal modes and their shadow radius. In addition, we find that, upon variation, the parameters of the theory show different aspects of the optical characteristics of the black hole solutions. This work has been done in collaboration with Aradhya Shukla and Sudhaker Upadhyay.

Exact nonsingular black holes and thermodynamics

We show that regular black holes given by Culetu can be obtained by coupling Einstein's gravity with the nonlinear electrodynamics source. The non-singular black hole has a mass function , k is the deviation parameter, and it interpolates between the Schwarzschild black hole ($r = 0$) and the Reissner-Nordstrom black hole (rk). Interestingly, there exists a critical mass parameter $M = M_c$, which corresponds to an extremal black hole when Cauchy and event horizons coincide. For $M > M_c$, it describes a nonextremal black hole with two horizons and no black hole for $M < M_c$. The Hawking temperature of the nonsingular black hole is maximum, where the specific heat diverges and changes its sign at the value of mass $M_{c2} > M_{c1}$, and the second-order phase transition occurs at that point. The smaller nonsingular black holes are always stable due to positive heat capacity and negative free energy. A discussion on the quasinormal modes of scalar field perturbations on nonsingular black holes background is included. This work has been done in collaboration with Sushant G. Ghosh .

Gyan P. Singh

Cosmological study with hyperbolic solution in modified $f(Q,T)$ gravity theory.

This work investigates the background of flat FLRW metric within the framework of $f(Q,T)$ gravity theory. We construct two cosmological models whose functional form in $f(Q,T)$ formalism are considered as (i) $f(Q,T) = \beta Q + \gamma T$ and (ii)$f(Q,T) = \beta Q^{n+1} + \gamma T$. To achieve an exact solution of highly nonlinear modified field equations, we have taken the parameterization of the scale factor as a hyperbolic function. The behavior of physical parameters viz. energy density (ρ), pressure (p), and equation of state parameter (ω) for appropriate choice of model parameters b, c, and n is obtained and that supports the accelerating expansion of the cosmic universe. We have discussed all the energy conditions NEC, WEC, DEC, and SEC to test the self-stability and self-consistency of the models. Additionally, the validity of our model is checked via Jerk, Snap, and Statefinder diagnostic parameters. This work has been done in collaboration with A. R. Lalke.

Cosmic dynamics and qualitative study of Rastall model with spatial curvature

We investigate the cosmic dynamics of Rastall gravity in non-flat Friedmann-Robertson- Walker (FRW) space-time with barotropic fluid. In this context, we are concerned about the class of model satisfying the affine equation of state. We derive the autonomous system for the Rastall model with barotropic fluid. We apply the derived system to investigate the critical points for expanding and bouncing cosmologies and their stable nature and cosmological properties. The expanding cosmology yields de Sitter universe at late times with decelerating past having matter and radiation dominated phases. Investigation of autonomous system for bouncing cosmology yields oscillating solutions in positive spatial curvature region. We also investigate the consequences of setting-up a model of non-singular universe by using energy conditions. The distinct

features of the Rastall model compared to the standard model have been discussed in detail This work has been done in collaboration Ashutosh Singh, and Anirudh Pradhan.

Newton Singh

Anisotropic Strange Star Model beyond Standard Maximum Mass Limit by Gravitational Decoupling in $f(Q)$ Gravity

The current theoretical development identified as the gravitational decoupling via Complete Geometric Deformation (CGD) method that has been introduced to explore the nonmetricity Q effects in relativistic astrophysics. In the present work, we have investigated the gravitationally decoupled anisotropic solutions for the strange stars in the framework of $f(Q)$ gravity by utilizing the CGD technique. To do this, we started with Tolman metric ansatz along with the MIT Bag model equation of state related to the hadronic matter. The solutions of the governing equations of motions are obtained by using two approaches, namely the mimicking of the θ sector to the seed radial pressure and energy density of the fluid model. The obtained models describe the self-gravitating static, compact objects whose exterior solution can be given by the vacuum Schwarzschild Anti-de Sitter spacetime. In particular, we modeled five stellar candidates, viz., LMC X-4, PSR J1614-2230, PSR J0740+6620, GW190814, and GW 170817 by using the observational data. The rigorous viability tests of the solutions have been performed through regularity and stability conditions. We observed that the nonmetricity parameter and decoupling constant show a significant effect on stabilizing to ensure the physically realizable stellar models. The innovative feature of this work is to present the stable compact objects with the masses beyond the $2M_{\odot}$ without engaging of exotic matter. Therefore, the present study shows a new perception and physical significance about the exploration of ultra-compact astrophysical objects. This work has been done in collaboration with S. K. Maurya, Santosh V. Lohakare and B. Mishra.

Observational Constraints on Maximum Mass Limit and Physical Properties of Anisotropic Strange Star Models by Gravitational Decoupling in Einstein-Gauss-Bonnet Gravity

In this work, we are guided by the gravitational wave events GW 170817 and GW 190814 together with observations of neutron stars PSR J1614-2230, PSR J1903+6620 and LMC X-4 to model compact objects within the framework of Einstein-Gauss-Bonnet (EGB) gravity. In addition, we employ the complete gravitational decoupling method to explore the impact of anisotropy by varying the decoupling parameter. We model strange quark stars in which the interior stellar fluid obeys the MIT Bag equation of state which represents a degenerated Fermi gas comprising of up, down, and strange quarks. In order to close the system of field equations describing the seed solution, we employ the Buchdahl ansatz for one of the metric functions. The θ sector is solved under the bifurcation: $\epsilon = \theta_0^0$ and $P_r = \theta_1^1$ leading to two new families of solutions. In order to test the physical viability of the models, we vary the EGB parameter (α) or the decoupling constant (β) to achieve the observed masses and radii of compact objects. Our models are able to account for low-mass stars for a range of β values while α is fixed. Our models mimic the secondary component of the GW 190814 with a mass range of 2.5 to 2.67 $M_{\odot}$ and radii typically of the order of $11.76^{+0.14}_{-0.19}$ km for large values of the EGB parameter and the decoupling constant. The energy exchange between fluids inside the stellar object is sensitive to model parameters which lead to stable configurations. This work has been done in collaboration with S. K. Maurya, M. Govender and Saibal Ray.

Monika Sinha

Compact star merger events with stars composed of interacting strange quark matter

We investigate the properties of stars participating in double compact star merger events considering interacting model of stable strange quark matter. We model the matter making it compatible with the recent astrophysical observations of compact star mass-radius and gravitational wave events. In this context we consider modified MIT bag model and vector bag model with and without self interaction. We find new upper bound on tidal deformability of 1.4 $M_{\odot}$ strange star corresponding to the upper bound of effective tidal deformability inferred from gravitational wave event. Range of compactness of 1.4 $M_{\odot}$ strange star is obtained as $0.175 \leq C_{1.4} \leq 0.199$. Radius range of $1.5M_{\odot}$ primary star is deduced to be $10.57 \leq R_{1.5} \leq 12.04$ km, following stringent GW170817 constraints. GW190425 constraints provide with upper limit on radius of 1.7 solar mass strange star that it should be less than 13.41

km. This work has been done in collaboration with Anil Kumar, and Vivek Baruah Thapa.

Hybrid stars are compatible with recent astrophysical observations

Compact stars (CS) are stellar remnants of massive stars. Inside CSs the density is so high that matter is in subatomic form composed of nucleons. With increase of density of matter towards the centre of the objects other degrees of freedom like hyperons, heavier non-strange baryons, meson condensates may appear. Not only that at higher densities, the nucleons may get decomposed into quarks and form deconfined strange quark matter (SQM). If it is so then CSs may contain SQM in the core surrounded by nucleonic matter forming hybrid stars (HSs). However, the nature and composition of matter inside CSs can only be inferred from the astrophysical observations of these CSs. Recent astrophysical observations in terms of CS mass-radius (M-R) relation and gravitational wave (GW) observation indicate that the matter should be soft in the intermediate density range and stiff enough at higher density range to attain the maximum possible mass above 2 $M_{\odot}$ which is not compatible with pure hadronic equation of states (EOSs). Consequently, we study the HS properties with different models of SQM and find that within vector bag model considering density dependent bag parameter, the model goes well with the astrophysical observations so far. This work has been done in collaboration with Anil Kumar, and Vivek B. Thapa.

K. Sriram

Type-B QPOs in the black hole source H1743-322 and their association with Comptonization region and Jet

The connection of type-B quasi-periodic oscillations (QPOs) to the hot flow in the inner accretion disc region is vaguely understood in black hole X-ray binaries. We performed spectral and timing studies of 23 observations where type-C and type-B QPOs with similar centroid frequencies (∼6 Hz) occurred. Their spectral differences were used to understand the production mechanism of type-B QPOs, along with the quasi-simultaneous radio observations. Based on the spectral results, we did not notice many variations in the Comptonization parameters and the inner disc radius during type-C and type-B QPOs. We found that the structure of the Comptonization region has to be different for observations associated with type-C and type-B QPOs based on the CompTT model. Radio flux density versus QPO width, soft to hard flux ratio, and QPO width versus inner disc temperature, were found to follow certain trends, suggesting that a jet could be responsible for the type-B QPOs in H1743-322. Further studies are required to uniquely constrain this scenario. In a case study where a gradual transition from type-C to type-B QPO was noticed, we found that the spectral changes could be explained by the presence of a jet or a vertically extended optically thick Comptonization region. The geometrical Lense-Thirring precession model with a hot flow and a jet in the inner region was incorporated to explain the spectral and timing variations. This work has been done in collaboration with S. Harikrishna.

Anticorrelated lags in a neutron star Z source GX 5-1: AstroSat's View

We report the cross-correlation function studies of a neutron star low-mass X-ray binary, a Z source GX 5-1, using Soft X-ray Telescope (SXT) and Large Area X-ray Proportional Counter (LAXPC) energy bands onboard AstroSat. For the first time, we report the lag between soft (0.8-2.0 keV, SXT) and hard X-ray energy bands (10-20 and 16-40 keV, LAXPC) in GX 5-1 and detected lags of the order of a few tens to hundreds of seconds in the horizontal branch. We interpreted them as the readjustment time-scale of the inner region of the accretion disc. We used various two components and three-component spectral models to unfold the spectra and observed the changes in soft and hard component fluxes that were exhibiting horizontal branch oscillation variations. It was observed that the bbody component assumed to be originating from the boundary layer over the NS and was also found to vary along with the HBO variation where lags were detected. We constrained the size of the comptonizing region of the order 15-55 km, assuming that lags were due to variation in the size of the corona. We noticed a similar size of the comptonizing region after employing other models and suggest that the overall size of corona must be of the order of a few tens of km to explain the lags, HBO variation, and respective spectral variations. In a case study, it was noted that the BL size increases as GX 5-1 vary from the top of the HB to the upper vertex. This work has been done in collaboration with P. Chiranjeevi.

Parijat Thakur

AstroSat View of the Newly Discovered X-Ray Transient MAXI J1803–298 in the Hard-intermediate State

We perform comprehensive temporal and spectral analysis of the newly discovered X-ray transient MAXI J1803–298 using an AstroSat target of opportunity observation on 2021 May 11 during its outburst. The source was found to be in the hard-intermediate state. We detect type C quasi-periodic oscillations (QPOs) at the frequencies of $\sim$ 5.4 and $\sim$ 6.3 Hz along with a subharmonic at $\sim$ 2.8 Hz in the $3-15$ keV band. The frequency and fractional rms amplitude of the QPO in the $15-30$ keV band are found to be higher than those in the $3-15$ keV band. We find soft lags of $\sim$ 3.8 and $\sim$ 6.8 ms for the respective QPOs at $\sim$ 5.4 and $\sim$ 6.3 Hz, whereas a soft lag of $\sim$ 4.7 ms is found at the subharmonic frequency. The increase in the soft lags at the QPO frequencies with energy is also observed in other black hole transients and attributed to the inclination dependence of the lags. The rms energy spectra indicate the power-law component to be more variable than the disk and reflection components. We find a broad iron line with an equivalent width of $\sim 0.17-0.19$ keV and a reflection hump above $\sim$ 12 keV in the energy spectrum. Based on the X-ray spectroscopy and considering the distance to the source as 8 kpc, the estimated mass ($\sim 8.5-16$ $M_{\odot}$) and spin ($a \gtrsim 0.7$) of the black hole suggest that the source is likely to be a stellar mass Kerr black hole X-ray binary. This work has been done in collaboration with Swadesh Chand, G. C. Dewangan, Prakash Tripathi, and V. K. Agrawal.

Revisiting the Transit Timing Variations in the TrES-3 and Qatar-1 Systems with TESS Data

We present and analyze 58 transit light curves of TrES-3b and 98 transit light curves of Qatar-1b, observed by the Transiting Exoplanet Survey Satellite, plus two transit light curves of Qatar-1b, observed by us, using a ground-based 1.23 m telescope. These light curves are combined with the best-quality light curves taken from the Exoplanet Transit Database and the literature. The precisely determined midtransit times from these light curves enable us to obtain the refined orbital ephemerides, with improved precision, for both hot Jupiters. From the timing analysis, we find indications of the presence of transit timing variations (TTVs) in both systems. Since the observed TTVs are unlikely to be short-term and periodic, the possibility of additional planets in orbits close to TrES-3b and Qatar-1b is ruled out. The possible causes of long-term TTVs, such as orbital decay, apsidal precession, the Applegate mechanism, and line-of-sight acceleration, are also examined. However, none of these possibilities are found to explain the observed TTV of TrES-3b. In contrast to this, line-of-sight acceleration appears to be a plausible explanation for the observed TTV of Qatar-1b. In order to confirm these findings, further high-precision transit and radial velocity observations of both systems would be worthwhile. This work has been done in collaboration with Vineet Kumar Mannaday, John Southworth, Ing-Guey Jiang and et al.

Vinutha Tummala

The study of hypersurface-homogeneous space-time in Renyi holographic dark energy

The investigation of this work is carried on the hypersurface-homogeneous space-time in the presence of two fluids, one being the pressureless matter and the other being the Renyi holographic dark energy (RHDE). Eventually, this work solves the cosmological model with Renyi HDE by taking the Hubble horizon as an infrared (IR) cutoff (L=$H^{-}1$). The geometrical and matter parts of space-time are solved within the Saez–Ballester scalar-tensor theory of gravitation. Interestingly, this study obtains a time-varying deceleration parameter (q) that exhibits a transition from deceleration to acceleration phase. For the configurations of parameter K emerging in space-time, three physically plausible cosmological hypotheses of the cosmos are outlined in this work. The kinematical properties were obtained and discussed for the three values of K. The study of cosmic expansion in the accelerated phase of this work is done through various cosmological parameters like EoS, deceleration parameter, statefinder parameter, etc. The Hubble parameter is derived in terms of cosmic time and redshift both. The present value of this parameter is estimated by taking 25 point data sets of observational Hubble data (OHD). The stability of the model is verified through the analysis of squared speed of sound ($v^2{}_s$) parameter. In this work, the obtained results match with recent observational data. This work has been done in collaboration with K. Venkata Vasavi, and K. Sri Kavya.

S. K. Tripathy

Dynamical system analysis for accelerating models in non-metricity $f(Q)$ gravity

Two accelerating cosmological models are presented in symmetric teleparallel $f(Q)$ gravity, Q be the non-metricity. The models are constructed based on the assumptions of two different functional forms of $f(Q)$ and a dynamically changing nature of the deceleration parameter that shows transition at $t = 2n \pm \sqrt{\frac{4n^2+1}{3}}$, n being a positive constant. In both the models, the equation of state parameter for the dark energy in $f(Q)$ gravity becomes a dynamical quantity and crosses the phantom divide line. The violation of the strong energy condition and the null energy condition at late times are also established. In addition, the dynamical system analysis has been performed and three critical points in each model are identified. In each model, at least one stable node has been observed. To strengthen further, the stability analysis using homogeneous linear perturbations has been performed to ensure the stability of the models This work has been done in collaboration with S. A. Narawade, L. Pati, and B. Mishra.

Evolution of Generalized BransDicke Parameter within a Superbounce Scenario

We studied a superbounce scenario in a set up of the Brans(BD) theory. The BD parameter was considered to be time-dependent and was assumed to evolve with the BransDicke scalar field. In the superbounce scenario, the model bounced at an epoch corresponding to a Big Crunch provided the ekpyrotic phase continued until that time. Within the given superbounce scenario, we investigated the evolution of the BD parameter for different equations of state. We chose an axially symmetric metric that has an axial symmetry along the x-axis. The metric was assumed to incorporate an anisotropic expansion effect. The effect of asymmetric expansion and the anisotropic parameter on the evolving and non-evolving parts of the BD parameter was investigated. This work has been done in collaboration with S. K. Pradhan, B. Barik, Z. Naik and B. Mishra.

Rashmi Uniyal

Tidal forces around Schwarzschild black hole in cloud of strings and quintessence

We study the tidal forces and their effect in Schwarzschild black hole surrounded with clouds of strings and quintessence. Two horizons are present for this black hole and the event horizon shrinks on increasing the values of both, the string cloud and quintessence parameters. Tidal forces in radial as well as angular directions are independent of string cloud parameter a. Geodesic deviation equations are devised and solved for this BH metric. For numerical representation of the solutions of geodesic deviation equations two different initial conditions have been applied. Results are compared with that of Schwarzschild black hole metric.

Sudhaker Upadhyay

Effect of GUP on the large scale structure formation in the universe

We study the clustering of galaxies in generalized uncertainty principle (GUP)modified Newtonian potential. We compute the corrected N-particle partition function which leads to the modified equations of state. The GUP corrected clustering parameter is compared with the original clustering parameter. An investigation of the distribution function for the system of galaxies is also made. Moreover, we analyze the effect of GUP on the two-point correlation function of the system. In order to find the optimal value of the clustering parameter we perform data analysis and compare our model with the data This study has been done in collaboration with A.W. Khanday, and P. A. Ganai.

Swampland dS conjecture in mimetic $f(R,T)$ gravity

In this paper, we study a theory of gravity called mimetic $f(R,T)$ in the presence of swampland dS conjecture. For this purpose, we introduce several inflation solutions of the Hubble parameter $H(N)$ from $f(R,T) = R + \delta T$ gravity model, in which R is Ricci scalar, and T denotes the trace of the energy-momentum tensor. Also, δ and N are the free parameter and a number of e-fold, respectively. Then we calculate quantities such as potential, Lagrange multiplier, slow-roll, and some cosmological parameters such as n_s and r. Then we challenge the mentioned inflationary model from the swampland dS conjecture. We discuss the stability of the model and investigate the compatibility or incompatibility of this inflationary scenario with the latest Planck observable data. This study has been done in collaboration with S. N. Gashti, J. Sadeghi.

Anisul Ain Usmani

Magnetic-field Induced Deformation in Hybrid Stars

We study the effects of strong magnetic fields on the deconfinement phase transition expected to take place in the interior of massive neutron stars. For hadronic matter, we use density-dependent relativistic mean field model with the DD-MEX parameter set, while effective vector-enhanced bag model is used to study quark matter. Magnetic-field effects are incorporated into the matter equation of state and in the general-relativity solutions, which satisfy Maxwell's equations. We find that for large values of magnetic dipole moment, the maximum mass, canonical mass radius, and dimensionless tidal deformability obtained for stars using spherically symmetric Tolman-Oppenheimer-Volkoff (TOV) equations and axisymmetric solutions attained through the LORENE library differ considerably.

Murli M. Verma

Unified $f(R)$ gravity at local scales

We explore the shifted $f(R)(\propto R^{1+\delta})$ model with δ as a distinguishing physical parameter for the study of constraints at local scales. The corresponding dynamics confronted with different geodesics (null and non-null) along with their conformal analog are investigated. For null geodesics, we discuss the light deflection angle, whereas, for non-null geodesics under the weak field limit, we investigate the perihelion advance of the Mercury orbit in $f(R)$ Schwarzschild background, respectively. The extent of an additional force, appearing for non-null geodesics, depends on δ. Such phenomenological investigations allow us to strictly constrain δ to be approximately $\mathcal{O}(10^{-6})$ with a difference of unity in orders at galactic and planetary scales and seem to provide a unique $f(R)$ at local scales. Our results suggest that the present form of the model is suitable for the alternative explanation of dark matter-like effects at local scales. This work has been done in collaboration with Vipin Kumar Sharma.

Effect of the Modified Gravity on the Large-scale Structure Formation

We investigate the formation of the large-scale structures in the present accelerated era in the f(R) gravity background. This is done by considering the linear growth of matter perturbations at low redshift $z < 1$. The effect of $f(R)$ alters the behavior of the matter density perturbations from the matter-dominated universe to the late-time accelerated universe, which is encoded in the Newtonian gravitational constant as $G \to G_{eff}$. The modified gravitational constant (G_{eff}) depends on the form of $f(R)$. The late-time accelerated expansion affects the formation of large-scale structures by slowing down the growth of matter density. On the other hand, $f(R)$ increases the growth rate of the matter density perturbations. We have found that the source term in the $f(R)$ background, $G_{eff}\Omega_m$, overcomes the accelerated expansion and the effect of accelerated expansion suppresses the formation of the large-scale structures in the asymptotic future. This work has been done in collaboration with Ajay Kumar Sharma.

Nilkanth Vagshette

Stellar and dust properties in a sample of blue early type galaxies

This paper presents a comparative study of physical properties of a sample of 89 blue early-type galaxies (ETGs) from the local universe by fitting SEDs to their multi-wavelength photometric and spectroscopic data. The detailed template-based SED fitting analysis using the MAGPHY S and SED3FIT codes on the interstellar dust extinction corrected UV-to-far-IR spectro-photometric data enabled us to trace the evolutionary sequence of the blue ETGs on the color-magnitude diagram. This study evidenced a decreasing trend of the SFR, sSFR, dust mass, and dust mass fraction over the sequence from the SF - to - the Seyferts - to - the LINERs. The UV-optical colors also enabled us to estimate the look-back time of the last starburst phase in SF, Seyfert, and LINER galaxies, probably pointing towards the evolutionary sequence of the blue ETGs. Despite the blue colors and strong emission lines in the optical regime of the electromagnetic spectrum, the blue ETGs in the present sample occupy a position off the main sequence, commonly known as the green valley, on the CMD plot and hence indicate the transitional state of their non-secular evolution. A marginal positive correlation was noticed between SFR per unit dust mass and the temperature of the cool ISM. The declining trend of the cold dust temperature Tc over the sequence from the SF-to-Seyfert-to-LINER implies that the AGNs in the systems are not enough powerful to affect the cold component of the ISM. This work has been done in collaboration with S. P. Deshmukh, and M. K. Patil.

IUCAA CENTRES FOR ASTRONOMY RESEARCH AND DEVELOPMENT (ICARDs)

Department of Physics and Electronics, Christ (Deemed to be University): Activities from 01 April 2022 till 31 March 2023

Coordinator:
Dr. Shivappa Bharamappa Gudennavar

Area of Research:

Stellar Physics; Interstellar Medium; High-Energy Astrophysics - X-ray Astronomy; Cosmology - Dark Matter and Dark Energy; Extragalactic Astronomy; Astronomical Instrumentation and Radio Astronomy.

Research Work and Collaborations:

Faculty members and PhD students of the Department are involved in collaborative research work with IUCAA, IIA, RRI and TIFR faculty members through joint supervision and research projects.

List of Seminars/Workshops/Schools organized:

National Seminar on Advances in Astrophysics and Space Science Research was organized during February 13-15, 2023.

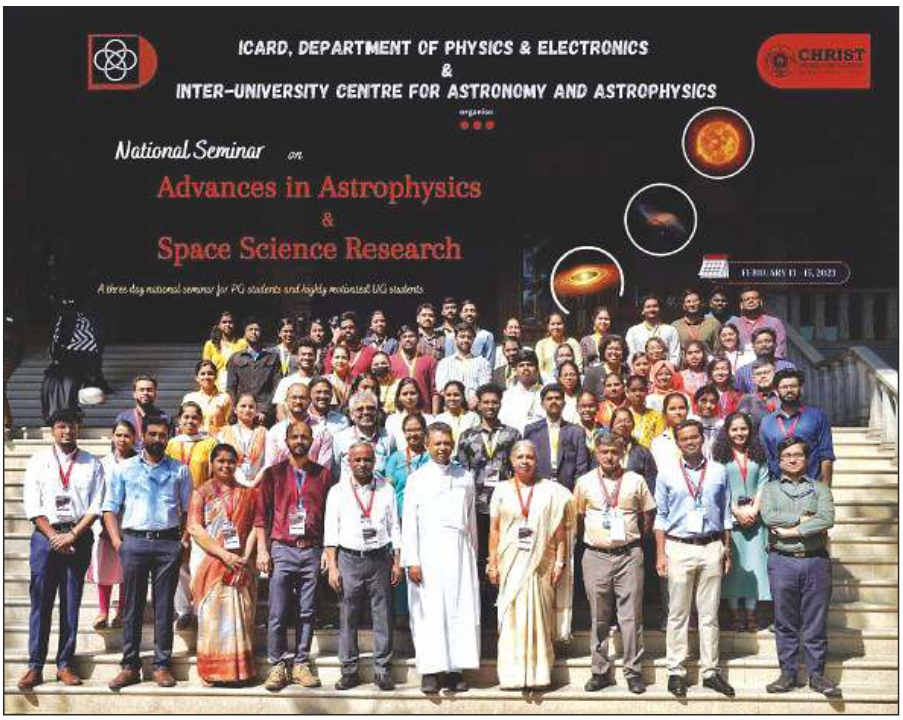
IUCAA Centre for Astronomy Research and Development (ICARD) at the Department of Physics and Electronics, CHRIST University, Bangalore organised a three-day National Seminar on '*Advances in Astrophysics and Space Science Research*' during February 13 - 15, 2023. The seminar was aimed to provide postgraduate and motivated undergraduate students the insights and knowledge on current developments in Astronomy and Astrophysics. There were over 40 participants, who attended the seminar representing the different parts of the country. The seminar covered talks on recent advances in astronomy and astrophysics by eminent scientists (Prof. Annapurni Subramaniam, IIA; Prof. Ajith Parmeswaran, ICTS; Prof. Dipankar Banerjee, ARIES; Dr. Shyama Narendranath K. C. ISAC-ISRO; Dr. Dipanjan Mukherjee, IUCAA; Dr. Smitha Subramanian, IIA; Dr. Vaidehi S. Paliya, IUCAA and Dr. Tapas Baug, SNBNCBS), contributory talks and posters by the participants, hands-on data analysis sessions and panel discussion.

Publications using ICARD facility:

Many articles have been published by the faculty members of the Department during the report period in the areas mentioned above. These are all the outcomes of funded projects and collaborations.

Talks delivered/organized:

All the faculty members of the Department working in Astronomy have delivered invited talks in the regional and state level meetings. The Department has also organized a few Guest Lectures and Colloquia on recent developments in Astrophysics.



ICARD, Department of Physics, Cooch Behar Panchanan Barma University (CBPBU): Activities from 01 April 2022 till 31 March 2023

Coordinator:
Dr Ranjan Sharma

Areas of Research: Theoretical Astro-particle physics and Cosmology.

The main research areas pursued by the faculty members and research scholars of the ICARD, CBPBU include probing of relativistic compact objects, gravitational collapse, dark matter and dark energy and applications of some extended theories of gravity.

List of workshops/schools organised by ICARD:

1. ICARD, CBPBU organized a two-day national seminar titled "General Relativity and Gravitation" at the university (main) campus during 22-23 November 2022. The seminar was meant to introduce the participants to the fundamentals of General Relativity and Gravitation and give a flavour of recent progress in astrophysics and cosmology. The seminar was attended by more than eighty participants (post-graduate students, research scholars and faculty members) from nearby colleges and universities.

As a Visiting Professor, Prof. Kanak Saha of IUCAA delivered a lecture series to the 4th Semester students of the department during 03-11 June 2022

Publications by using ICARD facilities:

1. K. Komathiraj, Ranjan Sharma and S. Chanda (2022), Efects of electric field and anisotropy on the mass-radius relationship of a particular class of compact stars,, Astrophys. Space Sci. (2022) 367:86; https://doi.org/10.1007/s10509-022-04119-5

2. Bikash Chandra Paul, Shyam Das, Ranjan Sharma (2022), Anisotropic compact objects with colour-flavour-locked equation of state in Finch and Skea geometry, Eur. Phys. J. Plus 137:525; https://doi.org/10.1140/epjp/s13360-022-02746-z

3. Shyam Das, Bikram Keshari Parida, Ranjan Sharma and Farook Rahaman (2022), Central pressure-dependent compact anisotropic stellar model and its tidal Love number, Eur. Phys. J. Plus 137:1092; https://doi.org/10.1140/epjp/s13360-022-03292-4

4. S. Thirukkanesh, I. Saparamadu, Ranjan Sharma and S. Bhattacharya (2022), Models for charged relativistic spheres via hyper-geometric equations, Pramana-j. of phys. 96:183; https://doi.org/10.1007/s12043-022-02424-w

5. B. Das, K. B. Goswami, P. K. Chattopadhyay, Ranjan Sharma (2023), Core-envelope model of an anisotropic strange star with density-dependent Bag (B) parameter, Indian J. of Phys.; https://doi.org/10.1007/s12648-023-02586-2.

6. Kunal Labar, A. Shankar, M. Das and Ranjan Sharma (2023), An insight on the origin of half-metallicity of new equiatomic quaternary Heusler alloys PtRuTiZ (Z = Al/Si): GGA and GGA + U approaches, Computational Materials Science 220, 112039 ; https://doi.org/10.1016/j.commatsci.2023.112039

7. Koushik Ballav Goswami, Anirban Saha and Pradip Kumar Chattopadhyay

(2022), Anisotropic compact star in modified Vaidya-Tikekar model admitting new solutions and maximum mass, Pramana-j of Phys., 96, DOI: https://doi.org/10.1007/s12043-022-02355-6

8. Koushik Ballav Goswami, Anirban Saha and Pradip Kumar Chattopadhyay (2022), Dependence of maximum mass of strange star on finite strange quark mass ($m_s \neq 0$), Class. Quantum Grav., 39, 175006, DOI: https://doi.org/10.1088/1361-6382/ac7f78

9. Koushik Ballav Goswami, Rohit Roy, Anirban Saha and Pradip Kumar Chattopadhyay (2022), Strange Quark Star (SQS) in Tolman IV potential with density dependent ⊗- parameter and charge, Euro. Phys. J. C, 82, 1042, DOI: https://doi.org/10.1140/epjc/s10052-022-11009-1

10. Anirban Saha, Koushik Ballav Goswami, Bishnu Das and Pradip Kumar Chattopadhyay (2022), Effect of charge on the maximum mass of anisotropic strange quark star, Pramana-j of Phys., 97, 10, DOI: https://doi.org/10.1007/s12043-022-02477-x

11. Anirban Saha, Koushik Ballav Goswami, Bishnu Das and Pradip Kumar Chattopadhyay (2023), Maximum mass of anisotropic charged strange quark stars in a higher dimensional approach ($D \geq 4$), Chinese Physics C, 47, 1, 015105, DOI: https://doi.org/10.1088/1674-1137/ac9aaa

12. Bishnu Das, Koushik Ballav Goswami, Anirban Saha & Pradip Kumar Chattopadhyay (2023), Anisotropic Strange Quark Star (SQS) in Finch-Skea geometry and its maximum mass for non-zero strange quark mass ($m_s \neq 0$), Chinese Physics C, 47, 5, 055101, DOI: https://doi.org/10.1088/1674-1137/acb90f

Outreach programmes, including public lectures/sky watch arranged by ICARD:

1. Dr Ranjan Sharma participated in the 8th Conference of the Polish Society on Relativity (POTOR8), during 19-23 September 2022 in Warsaw, Poland and delivered a talk titled 'Stiffness, complexity, cracking and stability of relativistic compacts star'.

2. As an invited speaker, Dr Ranjan Sharma delivered a talk at a seminar titled " Recent Trends in Modern Science" organised by Cooch Behar College, West Bengal, on 26 May 2022. The talk aimed at motivating undergraduate students to explore research opportunities in the field of astronomy, astrophysics and cosmology.

3. Dr Pradip Kumar Chattopadhyay presented a lecture on "Astronomy and Astrology: A basic difference" organised by "Paschimbanga Bigyan Mancha- North Bengal Unit" at Coochbehar Sadar School, Cooch Behar, West Bengal, on 17 February 2023

Glimpses of a seminar at ICARD, CBPBU during 22-23 November 2022

ICARD School of Physical and Applied Sciences Goa University, Goa: Activities from 01 Oct 2022 till 31 March 2023

Coordinator:
Dr. Reshma Raut Dessai

Workshop

The ISRO sponsored AstroSat Science Support Cell (ASSC) at IUCAA and Goa University organized an "Advanced Astrosat Data Analysis Workshop" from 9th to 15th January 2023 at Goa University. Prof. Ranjeev Misra, Prof. Gulab Dewangan, Prof. Dipankar Bhattacharyya, Prof. Kanak Saha and Dr. V. Girish delivered talks on different aspects of Astrosat. Different projects were assigned to the participants, involving imaging, photometric, spectral, and timing analysis of data from SXT, LAXPC, CZTI and UVIT instruments on board Astrosat. The primary component was team-wise extended hands-on sessions where participants analyzed AstroSat data in consultation with experts. 35 Ph.D. students were trained in the workshop.

Photo 1: Participants and the organisers of Advanced Astrosat data analysis workshop

Outreach Activities

1. **A public talk** was organised by School of Physical and Applied Sciences Goa University on the title "Observing Aditya (The Sun) with ISRO'S Aditya L1 mission on 14th January 2023 at Conference Hall Goa University. The speaker for the talk was Prof. Durgesh Tripathi, Faculty Inter University Centre for Astronomy and Astrophysics Pune.

Sky Observation and talk on Astronomy

2. As a part of extension and outreach programme following programmes were organized.

   Resource Person Dr. Reshma Raut Dessai, faculty SPAS, Goa University. The programme was attended by students, staff and the public.

Sr. No	Activities	Date	Location	No.
1	Sky Observation and talk on "Observational Astronomy and potential for space tourism"	30 November 2022	Shri. Shantadurga High school Bicholim, Goa	87
2	Sky observation and talk on Astronomy	22nd December 2022	St. Xavier's Higher secondary School Mapusa, Goa	70
3	Sky Observation and talk on "Observational Astronomy"	27th December 2022	Hanuman Vidnyalay Valpoi Sattari Goa	95
4	Sky Observation and talk on "Observational Astronomy and career in Astronomy"	25th February 2023	GVM's MIBK High School Khandepar, Goa	120
5	Sky Observation and talk on "Observational Astronomy"	31st March 2023	Xavier's College Mapusa, Goa	91
6	Sky Observation and talk on Astronomy	30th March 2023	Geology programme Goa University	56

Photo: Programme at Geology department Goa University

ICARD Department of Physics, DDU Gorakhpur University, Gorakhpur: Activities from 01 April 2022 till 31 March 2023

Coordinator:
Professor Shantanu Rastogi

Areas of Research:

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,
Gravity and Dark Matter,
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. Rajesh Kumar, DDUGU studies gravitational collapse and interacting models of dark matter and dark energy. Analysis of Astrosat observations by Sanjay Pandey, LBS Gonda. Continuous monitoring of atmospheric aerosols at Gorakhpur and study of satellite data on atmospheric trace gases are being carried out by Prabhunath Prasad and Shantanu Rastogi, DDUGU.

Publications by using ICARD facilities:

1. A comprehensive rotational study of astronomical iso-pentane within 84 to 111 GHz; A. Pandey, S. Srivastav, A. Vats, **A. Pathak**, K.A.P. Singh; Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 122299, 2023.

2. Rotational spectra of interstellar N-and CN-PAHs: pyrene and coronene; A. Vats, **A. Pathak**; Monthly Notices of the Royal Astronomical Society; 517 (4), 5780-5790, 2023.

3. Time-Dependent Density Functional Study of Nitrogen-Substituted Polycyclic Aromatic Hydrocarbons and Diffuse Interstellar Bands; N. Shukla, A. Vats, **A. Pathak**, G.A. Ahmed; ACS Earth and Space Chemistry, 6 (12), 2867-2876, 2022.

4. DFT study of Interstellar PANH: Vibrational spectra of anionic and cationic variants; G. Devi, **A. Pathak**, A. Vats; Advances in Space Research, 70 (7), 2133-2141, 2022.

5. Astrochemical model to study the abundances of branched carbon-chain molecules in a hot molecular core with realistic binding energies' S. Srivastav, M. Sil, P. Gorai, **A. Pathak**, B. Sivaraman, A. Das; Monthly Notices of the Royal Astronomical Society, 515 (3), 3524-3538, 2022

6. Laboratory Measurements of Stretching Band Strengths of Deuterated Quenched Carbonaceous Composites; T. Mori, T. Onaka, I. Sakon, M. Buragohain, N. Takahata, Y. Sano, **A. Pathak**; The Astrophysical Journal, 933 (1), 35, 2022.

7. Theoretical Study on Formamide (NH2CHO) and Methylidene (CH2) Reactions for the Formation of Interstellar N-Methylformamide; A. Ahamad, M. Singh, K. Singh, **A. Misra**, P. Tandon; Organic Chemistry Plus, 10-24, 2022.

8. Cosmological implications of an interacting model of dark matter & dark energy; K.R. Mishra, S.K.J. Pacif, **R. Kumar**, K. Bamba; Physics of the Dark Universe 40, 101211, 2023.

9. Dynamics of uniformly collapsing system and the horizon formation; A. Jaiswal, S.K. Srivastava, **R. Kumar**; International Journal of Geometric Methods in Modern Physics, 2350114, 2023.

10. Spherically symmetric collapsing star with the background of dark energy; G. Verma, **R. Kumar**, K.R. Mishra; International Journal of Geometric Methods in Modern Physics 19 (10), 2250148, 2022.

11. A dynamical model of radiating stars and their thermal behavior; G. Verma, **R. Kumar**; The European Physical Journal C, 82 (6), 513, 2022.

12. A new class of spherically symmetric gravitational collapse; **R Kumar**, A Jaiswal, Theoretical and Mathematical Physics 211 (1), 558-566, 2022.

13. Study of vibrational spectra of polycyclic aromatic hydrocarbons with phenyl side group; A. Maurya, R. Singh, **S. Rastogi**, J.Molecular Spectroscopy, 391, 111720, 2023.

14. Investigation of atmospheric turbulence and scale lengths using radiosonde measurements of GVAX-campaign over central Himalayan region; A. Rajput, N. Singh, J. Singh, **S. Rastogi**, J. Atmospheric and Solar-Terrestrial Phys., 235, 105895, 2022.

Activities/Outreach programmes:

1. Dr. Aditya Vaishya, Ahmedabad University, visited ICARD between 4 – 8 June 2022 for discussions regarding Aerosol observations from Gorakhpur.

2. Prof. **Amit Pathak**, BHU, Varanasi, visited on 11 June 2022 and gave lecture on Astrochemistry for MSc final students.

3. Prof. Dipankar Banerjee, ARIES, Nainital, visited on 5-6 December 2022, for discussions related to ongoing MoU between ARIES and DDUGU. Motivational interaction session with MSc students was organized.

4. **Prof. Shibesh K. Jas Pacif,** SGT University, Gurugram, delivered popular lecture on 'Structure of the Universe', Department of Mathematics and Statistics, DDUGU on 4 February 2023.

ICARD Department of Physics, Gauhati University, Guwahati, Assam: Activities from 01 April 2022 till 31 March 2023

Coordinator:
Dr. Sanjeev Kalita

Areas of research:

The ICARD at Department of Physics, Gauhati University was active from October 2022. It hosts research activities in gravitation & cosmology and observational astronomy.

Research works:

The department has two permanent faculty members in the field of Astronomy & Astrophysics. They are Sanjeev Kalita and Biman J Medhi. Currently there are 7 PhD students working in this field. They are provided with a dedicated research lab for their studies. The lab is equipped with networking facilities. Sanjeev Kalita is involved in the study of gravitation and cosmology and Biman J Medhi is involved in observational astronomy. The department also runs the Gauhati University Observatory for students' training in observational astronomy and public viewing of celestial objects.

In the field of gravitation and cosmology the following problems have been studied – (i) effect of dark matter distribution on modified gravity parameters near the Galactic Centre (GC) black hole, (ii) testability of f(R) gravity near the GC black hole through pericentre shift of orbits below SO-2 and (iii) constraining several spacetime metrics through the observed shadow of the GC black hole. In the first problem, exponential and power law dark matter profiles near the GC black hole were considered. By estimating the f(R) gravity scalaron field amplitude and gravitational potential near the black hole it was found that dark matter distribution can affect the screening and unscreening of f(R) scalarons. Low dark matter density naturally unscreens scalarons and high dark matter density screens the scalarons. It was found to be independent of the black hole spin. In the second study, difference between R^2 gravity and general relativity has been studied through pericentre shift of stellar orbits near the GC black hole. Effect of general relativity was found to be suppressed towards compact stellar orbits. In general f(R) models, scalarons with masses 10^{-16} eV are found to be screened and scalarons with mass range 10^{-22} ev – 10^{-19} eV are found to be unscreened near the orbit of SO-2. Testability of these scalarons through upcoming observations of Extremely Large Telescopes has been studied. In the problem of black hole shadow, the measured angular size of the shadow of the GC black hole has been used to constrain Kerr/Schwarzschild –de Sitter (KdS and SdS) metric, Reissner-Nordstrom (RN) metric with tidal charge and scalaron induced metric. Constraints on KdS, SdS and RN metric has been found to be stringent relative to M87* shadow. The

scalaron masses are narrowed down relative to the ones obtained from pericentre shift studies.

In the field of observational astronomy, X-ray spectrum variability of Mrk 478 has been studied using the observations from XMM-Newton, AstroSat and Swift. It has been found that for long – term (~ years) and intermediate – term (~ days to months) variability, the reflection fraction is anticorrelated with the flux and spectral index, which implies that the variability is due to the hard X-ray producing corona moving closer to and further from the black hole.

Publications by using ICARD facilities:

(1) Effect of dark matter distribution on scalaron gravity near the Galactic Center black hole and its prospects; P C Lalremruati [thesis work] and Sanjeev Kalita (pub. date 22nd December 2022), ApJ, 941, 183, 2022.

(2) Constraining spacetime metrics within and outside general relativity through the Galactic Center black hole (Sgr A*) shadow; **Sanjeev Kalita** and P. Bhattacharjee [research internship] (pub. date 5th February 2023), Eur. Phys. J. C 83, 120, 2023.

(3) Unscreening of f(R) gravity near the galactic center black hole: Testability through pericenter shift below SO-2's orbit; D. Paul [thesis work], **Sanjeev Kalita** and A. Talukdar [thesis work] (pub. date 16th February, 2023), IJMPD, 32, 2350021-91, 2023.

(4) Correlated variability of the reflection fraction with the X-ray flux spectral index for Mrk 478; S. Barua [thesis work], V. Jithesh, R. Misra, Biman J. Medhi and O. Adegoke (pub. date 23rd September 2022), MNRAS, 517, 801 (2022).

Public outreach events

The following sky viewing events were organised at Gauhati University Observatory.

(1) Planet observation program for college students; visit from Pandu College, Guwahati (3rd November, 2022). Research scholars of the department interacted with the students by illustrating on the naked eye planets.

(2) Public outreach event – "The wanderers in the Gauhati University sky" was organised to view the planets (11th January 2023).

(3) Planet observation and interaction program for college students; visit from Guwahati College, Guwahati (16th February 2023). Research scholars and faculty members of the department interacted with the students by illustrating on some bright stars and the planets.

ICARD Gurukula Kangri (Deemed to be University), Haridwar: Activities from 01 April 2022 till 31 March 2023

Coordinator:
Dr. Hemwati Nandan

Area 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

(a) We have investigated the orbits of spinning test particles around a Schwarzschild black hole under the influence of a quintessence matter field (SQBH). We begin with the dynamics of the spinning test particles around SQBH which is governed by the Mathisson–Papapetrou–Dixon equations under the pole–dipole approximation, where the gravitational field and the higher multipoles of the particle are neglected. Depending on the types of saddle points, the effective potential are classified and the possibility of chaotic orbits is discussed. The innermost stable circular orbits (ISCOs) of the spinning particle around SQBH are addressed, as are the effects of the parameters S (particles' spin) and ϵ (equation of state parameter). Later, Periastron precession is investigated up to the first-order spin correction for a spinning particle moving in nearly circular orbits around SQBH. It is noted that the addition of particle's spin revamps the results obtained for the non-spinning particles and also articulates some interesting observational properties of the SQBH. Additionally, we discuss the ramifications of employing first-order spin corrections for analysing ISCOs, as well as compare our results to the Schwarzschild BH to ensure that they are consistent in the limit when the equation of state parameter $\epsilon = -1/3$ and normalization factor $\alpha \rightarrow 0$.

(b) We have studied the stability of circular orbits in the background of a traversable wormhole (TWH) spacetime obtained as a solution of Einstein's 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 ~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.

© The null geodesics of the regular and rotating magnetically charged black hole in a non-minimally coupled Einstein-Yang-Mills theory surrounded by a plasma medium is studied. The effect of magnetic charge and Yang-Mills parameter on the effective potential and radius of photon orbits has investigated. We then study the shadow of a regular and rotating magnetically charged black hole along with the observables in the presence of the plasma medium. The presence of plasma medium affects the apparent size of the shadow of a regular rotating black hole in comparison with vacuum case. Variation of shadow radius and deformation parameter with Yang-Mills and plasma parameter has examined. Furthermore, the deflection angle of the massless test particles in weak field approximation around this black hole spacetime in the presence of homogeneous plasma medium is also investigated. Finally, we have compared the obtained results with Kerr-Newman and Schwarzschild black hole solutions in general relativity (GR).

(d) We analyze the stability of circular geodesics for timelike as well as null geodesics of the Kerr BH spacetime with rotation parameter on the equatorial plane by Lyapunov stability analysis. Also, we verify the results of stability by presenting the phase portrait for both timelike and null geodesics. Further, by reviewing the Kosambi-Cartan-Chern (KCC) theory, we analyze the Jacobi stability for Kerr spacetime and present a comparative study of the methods used for stability analysis of geodesics.

List of publications by using ICARD facilities:

(a) S. Giri, P. Sheoran, **H. Nandan** and S. Shaymatov, Chaos motion and Periastron precession of spinning test particles moving in the vicinage of a Schwarzschild black hole surrounded by a quintessence matter field, Eur. Phys. J. Plus, 138:245 (2023).

(b) S. Giri, **H. Nandan,** L. K. Joshi and S. D. Maharaj, Stability analysis of circular orbits around a traversable wormhole with massless conformally coupled scalar field, European Physical Journal C 82:298, (2022).

(c) S. Kala, **H. Nandan**, P. Sharma, Shadow and weak gravitational lensing of a rotating regular black hole in a non-minimally coupled Einstein-Yang-Mills theory in the presence of plasma, European Physical Journal Plus 137:457, (2022).

(d) P. Singh, **H. Nandan**, L. K. Joshi, N. Handa and S. Giri, Stability of circular geodesics in the equatorial plane of Kerr spacetime, European Physical Journal Plus 137:263, (2022).

Any outreach programmes, including public lectures/sky watch arranged by ICARD, etc.

(a) Sky watch programme in Science Week Festival during 28 Feb-03-Mar, 2023 in different campuses of HNBGU, Srinagar Garhwal.

(b) Sky watch programme during 19-21 Dec, 2022 at Chauras campus, HNBGU Srinagar Garhwal.

In above sky watch activities, more than 3000 students of our campus and nearby schools have participated in this programme to watch sunspots and night sky objects.

Any honours/distinctions/awards, etc. received by persons connected with ICARD

Extra-ordinary Professor (Honorary position) at Center for Space Research (CSR), North-West University, South Africa.

ICARD Department of Statistics, University of Calcutta, Kolkata: Activities from 01 April 2022 till 31 March 2023

Coordinator:
Professor Asis Kumar Chattopadhyay

Area of Research:

During this period 2022-23 the main focus of the research work was theoretical studies as well as data Analysis related to Astronomical Objects, Star formation Rate, Explosion Triggered Star Formation, Thermal Instability driven Star Formation, Distance Determination of nearby as well as far off stars, Measure of Chaos in the presence of SMBH under different halos, Episodic model of Star Formation with small scale dissipation. Some large scale simulation studies have been carried out. Some scholars and faculty members of different colleges and Universities in and around Kolkata are very much involved in the use of Mathematical and Statistical software as well as development of Computer programs for the appropriate analysis of Astronomical data. They are also trying to develop new statistical techniques appropriate for the analysis of Astronomical data.

Research Work done:

Some of research works carried out during this period are stated below:

(a) In the field of Astrostatistics, clustering and classification of different astronomical objects play a very important role. In cluster analysis, the objective is to group the items such that items in the same cluster are more closely related than those assigned to different clusters. The total number of clusters in the data set may be known in some cases and maybe unknown in others. There are different methods available for clustering, which can be further categorized under supervised and unsupervised learning techniques. In the case of supervised learning, there are some model assumptions but in the case of unsupervised learning, there are no such assumptions. Under both the above-mentioned categories, for clustering and classification, various methods have been developed depending on the nature of the data sets. However, generally, it is difficult to compare the performances of the different techniques. Here we have tried to compare the applicability of some of the clustering techniques on a galaxy data set. To justify the robustness of the variety of unsupervised methods used in our work, a few post-classification techniques are used as supervised learning. Finally, the comparability of clusters, obtained by different techniques, is studied with respect to an ad-hoc technique and they are further justified in terms of astrophysical properties of the galaxies. Our main focus is on unsupervised machine learning algorithms, which are used to perform dimensionality reduction, cluster analysis, visualization and to get an idea regarding the best-unsupervised technique that is appropriate for a galaxy data set. It is found that K-means performs best for the galaxy data set under consideration.

(b) We revisit the problem of clustering 1318 new variable stars found in the Milky way. Our recent work distinguishes these stars based on their light curves which are univariate series of brightness from the stars observed at discrete time points. This work proposes a new approach to look at these discrete series as continuous curves over time by transforming them into functional data. Then, functional principal component analysis is performed using these functional light curves. Clustering based on the significant functional principal components reveals two distinct groups of eclipsing binaries with consistency and superiority compared to our previous results. This method is established as a new powerful light curve-based classifier, where implementation of a simple clustering algorithm is effective enough to uncover the true clusters based merely on the first few relevant functional principal components. Simultaneously we discard the noise from the data study involving the higher order functional principal components. Thus the suggested method is very useful for clustering big light curve data sets which is also verified by our simulation study.

(c) The star formation histories and chemical evolution of a dwarf spiral galaxy NGC 2403 and a massive spiral galaxy NGC 628 are studied in this work through a simple chemical evolutionary model under the influence of several supernovae-driven galactic outflows. The galactic disk of each galaxy is considered as a collection of some concentric rings each of which evolves independently without exchanging matters among themselves. The disk is formed through continuous accretion of pristine gas from halo. A classical Kennicutt–Schmidt star formation law is taken into account with an exponential gas accretion rate. In order to analyze the impact of outflow, we have taken into account two separate types of supernovae-driven gas outflow, namely supernovae momentum-driven outflow and supernovae energy-driven outflow, both of which depend on the circular velocity of the disk. By comparing our model's anticipated result with observational data, the most viable models are chosen. For the dwarf galaxy NGC 2403, the supernovae energy-driven outflow model yields a better result which indicates that the supernovae energy-driven outflow mechanism plays a major role in driving the outflows in low mass galaxies. However, for NGC 628, both the outflow models adequately account for the observed features, suggesting that both momentum-driven and energy-driven outflows contribute equally to the outflows of the massive galaxy NGC 628. Furthermore, we contrasted the evolution of radial and global properties of these galaxies.

(d) We have tried to explore the origin of the formation of star clusters in our Galaxy and in the Small Magellanic Cloud (SMC) through simulated H-R diagrams and compare those with observed star clusters. The simulation study produces synthetic H-R diagrams through the Markov Chain Monte Carlo (MCMC) technique using the star formation history (SFH), luminosity function (LF), abundance of heavy metal (Z), and a big library of isochrones as basic inputs and compares them with observed H-R diagrams of various star clusters. The distancebased comparison between those two diagrams is carried out through two-dimensional matching of points in the color–magnitude diagram (CMD) after the optimal choice of bin size and appropriate distance function. It is found that in a poor medium of heavy elements (Z = 0.0004), the Gaia LF along with a mixture of multiple Gaussian distributions of the SFH may be the origin of formation of globular clusters (GCs). On the contrary, an enriched medium (Z = 0.019) is generally favored with the Gaia LF along with a double power law or Beta-type (i.e., unimodal) SFH, for the formation of globular clusters. For SMC clusters, the choice of an exponential LF and exponential SFH is the proper combination for a poor medium, whereas the Gaia LF with a Beta-type

SFH is preferred for the formation of star clusters in an enriched medium

List of publications by using ICARD facilities:

1. Star formation histories of dwarf and giant galaxies with different supernovae-drivenoutflows: NGC 2403, NGC 628 Suparna Sau , T**anuka Chattopadhya** , Pratap Ray New Astronomy, 2023, 100.

2. Investigation of the effect of bars on the properties of spiral galaxies: a multivariate statistical analysis, Prasenjit Banerjee, **Tanuka Chattopadhyay and Asis Kumar Chattopadhyay,** Communications in Statistics- Simulation and Computation, 2022.

3. Comparison among different clustering and classification techniques: Astronomical data dependent study, Prasenjit Banerjee, **Tanuka Chattopadhyay and Asis Kumar Chattopadhyay,** New Astronomy, 2023, 100.

4. Clustering of eclipsing binary light curves through functional Principal Component Analysis, Soumita Modak, **Tanuka Chattopadhyay and Asis Kumar Chattopadhyay**, Astrophysics and Space Science, 367 (Article id 19),2022.

5. A new measure for assessment of clustering based on kernel density estimation, Soumita Modak, Communications in Statistics - Theory and Methods, 2022,Doi: https://doi.org/10.1080/03610926.2022.2032168

6. A new nonparametric inter point distance based measure for assessment of clustering, Soumita Modak, Journal of Statistical Computation and Simulation, 2022, 92, 1062-1077

ICARD Department of Physics, Aliah University, Kolkata: Activities from 01 April 2022 till 31 March 2023

Coordinator:
Md. Mehedi Kalam

Area of Research:

General Relativity,
Theoretical Astrophysics,
Compact stars;
Dark matter;
Alternative Theory of Gravity;
Wormhole Physics,
Cosmology.

The Department of Physics, Aliah University has started functioning as a host of ICARD on and from 14th Sept. 2022 after receiving the approval from the competent authority. The Dept. of Physics has a strong teaching and research programme. Earlier a compulsory elective paper on "General Theory of Relativity and Astrophysics" and M.Sc. project on Astrophysics was offered to M.Sc. Final year students. From this semester in new CBCS curricula, we are offering two semester course (12 credit) in General Relativity, Astrophysics and Cosmology to M.Sc. students along with M.Sc. project (4 credit) on Astrophysics and Cosmology. 17 students are enrolled to take this course in new CBCS curricula.

Prof. Md. Mehedi Kalam, Coordinator, ICARD, Prof. Debades Bandopadhyay, Honorary Visiting Professor and Former Head, Astro-particle Physics Division, SINP, Dr. Sajahan Molla, a visiting associate of IUCAA, other associates of nearby institutions along with the research scholars of Astrophysics group are the active members of ICARD, Aliah University.

Research work done in ICARD : (Activities from 14th Sept. 2022 to 31st March 2023)

The members associated with ICARD, Aliah University have worked on different issues related to the areas of Astrophysics and Cosmology as mentioned earlier during the assessment period. We have worked on the possible existence of the dark-matter-admixed pulsars in the disk region of the Milky Way galaxy by using Navarro–Frenk–White (NFW) dark-matter density profile. Also, we have, together with other members, discussed an analytical model on low-mass strange stars based on the Heintzmann ansatz in (2+1) dimension. Attractive anisotropic force plays a significant role in restricting the upper mass limit (which is comparatively low) of the strange star. We have applied our model to some low-mass strange stars and see that it is useful to predict important parameters of the low-mass strange stars.

Also, we have investigated the possibility of presence of static, spherically symmetric and traversable Lorentzian wormholes in an emergent universe (EU). A non-singular emergent universe (EU) scenario within the realm of standard Relativistic physics requires a generalization of the equation of state (EoS) connecting the pressure and energy density. This generalized EoS is capable of describing a composition of exotic matter, dark energy and cosmological dust matter. Since the EU scenario is known to violate the null energy condition (NEC), we investigate the possibility of presence of static, spherically symmetric and traversable Lorentzian wormholes in an EU. The obtained shape function is found to satisfy the criteria for wormhole formation, besides the violation of the NEC at the wormhole throat and ensuring traversability such that tidal forces are within desirable limits. Also, the wormhole is found to be stable through linear stability analysis. Most importantly, the numerical value of the EU parameter *B*

as estimated by our wormhole model is in agreement with and lies within the range of values as constrained by observational data in a cosmological context. Also, the negative sign of the second EU parameter *A* as obtained from our wormhole model is in agreement with the one required for describing an EU, which further indicates on the existence of such wormholes in an EU without accounting for any additional exotic matter field or any modification to the gravitational sector.

Also, we have constructed a new class of five-dimensional (5D) thin-shell wormholes by the 'Cut–Paste' technique from black holes in Einstein–Gauss–Bonnet gravity inspired by non-commutative geometry starting with a static spherically symmetric, Gaussian mass distribution as a source and for this structural form of the thin-shell wormhole we have explored several salient features of the solution, viz., pressure–density profile, equation of state, the nature of wormhole, total amount of exotic matter content at the shell. We have also analyzed the linearized stability of the constructed wormhole. From our study we can assert that our model is found to be plausible with reference to the other model of thin-shell wormhole available in literature.

Colloquia/Seminars organized by ICARD: (Activities from 14th Sept. 2022 to 31st March 2023)

1. Colloquium Lecture delivered by Prof. Naresh Dadhich, Emeritus Professor & Former Director, IUCAA, Pune, Govt. of India on 25th November 2022.

   Title of the talk: Why Einstein (Had I been born in 1844!)? : Relativity for Everyone.

2. Colloquium Lecture (HYBRID MODE) delivered by Prof. Yashwant Gupta, Distinguished Professor and Centre Director, National Centre for Radio Astrophysics (NCRA), Tata Institute of Fundamental Research (TIFR), Pune University Campus, Pune, Govt. of India on 16th February 2023.

   Title of the talk: Probing the Universe using radio waves.

Publications by using ICARD facilities: (Activities from 14th Sept. 2022 to 31st March 2023)

Members of ICARD, Aliah University have published articles in the following journals:

[1] Possible Existence of Dark-Matter-Admixed Pulsar in the Disk Region of the Milky Way Galaxy. Nilofar Rahman,Masum Murshid, Sajahan Molla and **Mehedi Kalam,** Universe 8, 12, 652 (2022); Impact Factor- 2.813; Citation :00. https://doi.org/10.3390/universe8120652

[2] ––Thin-shell wormhole under non-commutative geometry inspired EinsteinGaussBonnet gravity. N Rahman, **Mehedi Kalam**, A Das, S Islam, F Rahaman, M Murshid, Eur. Phys. J. Plus 138, no. 146, 2, (2023) ; Impact Factor- 3.758; Citation :00 DOI: 10.1140/epjp/s13360-023-03764-1

[3] Analytical model of low-mass strange stars in 2+1 space-time. Masum Murshid, Nilofar Rahman, Irina Radinschi and **Mehedi Kalam,** Pramana -J Phys 97, no. 51, 1 (2023); Impact Factor-2.699; Citation :02, https://doi.org/10.1007/s12043-022-02508-7

[4] Lorentzian wormholes in an emergent universe. Rikpratik Sengupta, Shounak Ghosh, B.C.Paul and **Mehedi Kalam,** Class. Quant. Grav. 40, no. 9, 095009 (2023); Impact Factor-3.528; Citation :06, DOI: 10.1088/1361-6382/acc5d7

Prof. Naresh Dadhich,
Emeritus Professor & Former Director, IUCAA,
being felicitated by the
Prof. Mehedi Kalam (Coordinator,
ICARD) on 25th November 2022.

Prof. Yashwant Gupta,
Distinguished Professor and Centre Director,
National Centre for Radio Astrophysics (NCRA),
Tata Institute of Fundamental Research (TIFR)
was delivering the colloquium lecture (HYBRID MODE)
on 16th February 2023.

ICARD Department of Physics, CCASS, GLA University, Mathura: Activities from 01 April 2022 till 31 March 2023

Coordinator:
Prof. Saibal Ray

Area of Research:

Astronomy, Astrophysics,
Cosmology,
History and Philosophy of Science

One/two paragraphs about the research work done in ICARD:

Prof. Anirudh Pradhan and Dr. Ashutosh Singh have been working in the field of cosmology, classical GR as well as Modified gravity theories whereas Prof. Saibal Ray have done researches in the field of Astrophysics and History of Science.

List of publications by using ICARD facilities:

1. P. Garg, V.K. Bhardwaj and **A. Pradhan**, Barrow entropic quintessence and dilation dark energy models with generalized HDE cut-off, *Int. J. Mod. Phys. A* **37** (2022) 2250217.

2. A. Dixit and **A. Pradhan**, Bulk Viscous Flat FLRW Model with Observational Constraints in f (T, B) Gravity, *Universe* 8 (2022) 650.

3. **A. Pradhan**, A. Dixit and D.C. Maurya, Quintessence Behavior of an Anisotropic Bulk Viscous

4. Cosmological Model in Modified f(Q)-Gravity, *Symmetry* 14 (2022) 2630.

5. R.R. Sahoo, K.L. Mahanta, **S. Ray**, Nonsingular Phantom Cosmology in Five-Dimensional f (R, T) Gravity, *Universe* 8 (2022) 573.

6. G. Mustafa, S.K. Maurya and **S. Ray**, On the possibility of generalized wormhole formation in the galactic halo due to dark matter using the observational data within the matter coupling gravity formalism, *Astrophys. J.* 941 (2022) 170.

7. K. Chakraborty, F. Rahaman, **S. Ray**, B. Sen and D. Deb, Galactic Wormhole under Lovelock Gravity, *Universe* 8 (2022) 581.

8. **S. Ray**, S. Ghosh and R Sengupta, Gravastar under the framework of braneworld gravity II: Effect of the Kuchowicz metric function, *Mod. Phys. Lett. A* **37** (2022) 2250195.

9. I. Bhattacharyya and **S. Ray**, Accelerated motion in general relativity: fate of the singularity, *Eur. Phys. J. C* 82 (2022) 953.

10. S. Das, A. Panda, G. Manna and **S. Ray,** Raychaudhuri Equation in K-essence Geometry: Conditional Singular and Non-Singular Cosmological Models, *Fortschr. Phys.* 2023, 2200193.

11. P. Paul, R. Sengupta and **S. Ray**, Some studies on modified power law inflation, *Chin. Phys. C* 47 (2023) 035107.

12. L. Baskey, **S. Ray**, S. Das and S. Majumder, Anisotropic Compact Stellar Solution in General Relativity, *Eur. Phys. J. C* 83 (2023) 307.

13. K.P. Das, U. Debnath and **S. Ray**, Dark Energy Star: Physical Constraints on the Bounds, *Fortsch. Physik – Prog. Phys.* **2023**, 2200148**.**

14. S.K. Maurya, K.N. Singh, M. Govender and **S. Ray**, Complexity-Free Anisotropic Solution of Buchdahl's Model and Energy Exchange Between Relativistic Fluids by Extended Gravitational Decoupling, *Fortsch. Physik – Prog. Phys.* 2023, 2300023**.**

15. M. Indra, K.K. Ghosh and **S. Ray**, Analytical study of ion-acoustic solitary waves in a magnetized plasma with degenerate electrons, *Chin. J. Phys.* 81 (2023) 325.

16. J. Bulnes, **S. Ray**, R. Cruz-Santiago and J. López-Bonilla, Lorentz Transformation & the Intrinsic Geometry of a Time-like Curve in Minkowski Spacetime, *Prespacetime J.* 14 (2023) 354.

17. S.K. Maurya, K.N. Singh, M. Govender and **S. Ray**, Observational Constraints on Maximum Mass Limit and Physical Properties of Anisotropic Strange Star Models by Gravitational Decoupling in Einstein-Gauss-Bonnet Gravity, *Mon. Not. R. Astron. Soc.* 519 (2023) 4303.

18. S. Das, K. Chakraborty, L. Baskey, **S. Ray**, A study on the effect of anisotropy under Finch-Skea geometry, *Chin. J. Phys.* 81 (2023) 362.

19. G. Manna, A. Panda, A. Karmakar, **S. Ray**, M.R. Islam, *f[R,[L_x]]*-gravity in the context of dark energy with power law expansion and energy conditions, *Chin. J. Phys.* 47 (2023), 025101.

20. **S. Ray**, U. Mukhopadhyay and S. Dhurde, IUCAA: genesis of a unique research centre, *Eur. Phys. J. H* 48, 1 (2023)

21. S. Gupta, A. Dixit and **A. Pradhan**, Tsallis holographic dark energy scenario in viscous f(Q) gravity with tachyon field, *Int. J. Geom. Meth. Mod. Phys.* 20 (2023) 2350021

22. S.H. Shekh, N. Myrzakulov, **A. Pradhan** and A. Mussatayeva, Observational Constraints on F(T , TG) Gravity with Hubble's Parametrization, *Symmetry* 15 (2023) 321.

23. V.K. Bhardwaj, A. Dixit and **A. Pradhan**, Bianchi type-V transitioning model in Brans–Dicke theory with observational constraints, *Int. J. Geom. Meth. Mod. Phys.* 20 (2023) 2350022.

Any outreach programmes, including public lectures/sky watch arranged by ICARD:

(i) An event with a popular talk in the school Kanya Purva Maadhyamik Vidhyalay, Chaumuhan, Mathura held on 17 February 2023 at 12:30-2:30 PM. The topic of the talk was "The story of the Universe" delivered by Prof. Saibal Ray for the students of classes 6 - 8, the reactions of the students revealed that this type of seminars are of emergent need for the rural students to promote basic knowledge of Astronomical sciences. In the event, 100 students were provided notebooks and pens. The Principal of the school has expressed her gratitude with an earnest desire to continue this kind of programme in the future.

(ii) An event of popular seminar on "Active galaxies, Black Holes and Binary Black Holes" by Dr. Pankaj Kushwaha, Assistant Professor, IISER, Mohali was held on 20 February 2023 at 11:00-12:30 PM in the Centre for Cosmology, Astrophysics and Space Science, GLA University, Mathura. It was a grand success with the seminar hall full of the audiences includes B. Tech., BCA, B.Sc., M.Sc. and Ph.D. students with a number more than 100. Prof. A. K. Beesham, South Africa along with other faculty members of GLA University were present in the event. A lively interactive session occurred between the speaker and the students, which reveals that the audience have enjoyed the seminar, a lot.

(iii) An event with a popular talk on the Astrophysical events has been conducted in Uccha Prathamik Vidhyalay - Dvitiya, Ajhai Khurd, Mathura under ICARD on 24 March 2023 during 01:00-3:00 PM. The speaker for the event was Prof. Saibal Ray, CCASS, GLA University. The audience were the students from class 5 to 8 along with the teachers of the school. In the event, 143 students were present and they were provided notebooks and pens to each. The audience were curious enough which was proved from their silly as well as inquisitive questions on the theme of the lecture. The Principal of the school Smt. Anamika Saxena expressed her gratitude and invited for future events of this kind.

(iv) A popular seminar on the topic "Cosmological Models and Modified Gravity: Geometrical Interpretation" by Prof. Bivudutta Mishra, BITS-Pilani, Hyderabad Campus, was conducted on 31 March 2023 at 11:00 AM. The seminar hall was full of audience belonging to B.Sc., B. Tech, M.Sc. (Phys.) and research scholars. Some interested faculty members from the English, Mathematics, and Computer engineering departments were also present in the seminars. An interactive session with question from the student (in particular, UG students) on different issues of the universe-accelerated expansion and other cosmological issues which include Big-Bang model were discussed with the speaker in length. In the end, Prof. Mishra was felicitated by the Director, CCASS.

ICARD, School of Physical Sciences, S.R.T.M. University, Nanded: Activities from 01 April 2022 till 31 March 2023

Coordinator:
Dr. 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 ICARD activities are supported by 08 research scholars working in the field of Astronomy & Astrophysics and 20 M Sc Final Year students with Astrophysics specialization.

List of publications by using ICARD facilities:

1. S. P. Deshmukh, N. D. Vagshette and **M. K. Patil**; stellar and dust properties in a sample of blue early type galaxies; Serb. Astron. J., 205 (2022), 23 - 32 (DOI: https://doi.org/10.2298/SAJ2205023D)

2. Kiran Wani and Haritma Gaur**,** Study of Intra-Day Flux Distributions of Blazars Using XMM-Newton Satellite, Universe 2022, 8, 578 (DOI: https://doi.org/10.3390/universe8110578)

3. Kiran Wani, Haritma Gaur and **M. K. Patil;** X-ray studies of Blazar 1ES 1959+650 using Swift and XMM-Newton satellite, *2023, ApJ, in press.*

Conference presentations during year 2021-2022:

1. K. Wani, H. Gaur & **M. K. Patil**; Flaring activity of Blazar 4C +29.45 and BL Lacertae: Multiband Optical Variability, in the National conference on REcent Trends in the study of Compact Objects (RETCO-V): Theory and Observation, 10 February 2023**,** organized by IIT Roorkee and ARIES, Nainital (in online mode)

2. K. Wani, H. Gaur & **M. K. Patil**; *X-ray Studies of High Synchrotron Peaked Blazar 1ES 1959+650, 4th National Conference on High Energy Emission from ACTIVE GALACTIC NUCLEI held at Farook College, Calicut, Kerala, India*

during 12-14 August 2022

PhDs awarded during year 2021-2022:

1. **Dr. Bhagorao Tukaram Tate** received Ph D. in Physics from S.R.T.M. University, Nanded in April 13, 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. Dr. Satish Sonkamble, GMRT-TIFR, Pune
4. Mr. Rupesh Ghodpage, MF Radar, IIG, Kolhapur
5. Mr. Kiran Wani, Research Scholar, ARIES, Nainital
6. Mr. A. T. Kyadampure, Sanjivani Mahavidyalaya, Chapoli, Dist. Latur
7. B. Sc. Physics students and faculty from Gramin Mahavidyalaya, Kotgyal
8. Amateur Astronomy Club Members at Nanded
9. Post graduate students, teaching and non-teaching staff from campus schools
10. Students and Teachers from Swiss Academy English School, Parbhani
11. BA/B Com students and teachers from people's College, Nanded
12. School and College students from this region.

Any outreach programmes, including public lectures/sky watch arranged by ICARD, etc.

Faculty at the School of Physical Sciences, S.R.T.M. University, Nanded as a part of ICARD has carried out various activities during 2022-23 and have also delivered lectures in online as well as in physical mode 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 2023)

ii. Public outreach on the occasion of solar eclipse on October 25, 2022.

iii. Delivered a talk on "**World of Stars**" in the Lecture Series organized by Department of Physics, Karmaveer Mamasaheb Jagdale Mahavidyalaya, Washi, Dist - Osmanabad on March 1, 2023 as a part of Science Day Celebration.

iv. Delivered a talk on "**World of Galaxies**" on October 17, 2022 in the International Workshop on Science & Technology in Astronomy Research (STAR 2022) organized by School of Studies in Physics and Astrophysics, Pt. R.S. University, Raipur.

v. Arranged IUCAA SciPOP and Amateur Astronomers' Meet in the School of Physical Sciences of S.R.T.M. University, Nanded on October 2, 2022.

vi. Popular talk followed by observatory visit of students from Zilla Parishad High School, Kasmat, Tq. Kinwat, Dist. Nanded on December 24, 2022.

vii. Introductory talk followed by observatory visit of B. Sc. Physics students from Mahatma Basweshwar College, Latur on December 26, 2022.

viii. Acted as organising member of the LIGO-India: Star Fest – 2022 for the Zilla Parishad High School Science Teachers' from Hingoli District at Model Degree College of S.R.T.M. University, Hingoli on Auguust 5, 2022.

Delivered a talk on "**Career Opportunities in Astronomy**" for M Sc students of School of Physical Sciences, S.R.T.M. University, Nanded on November 12, 2022.

ICARD, Department of Physics and Astronomical Science, Central University of Himachal Pradesh, Shahpur Kangra: Activities from 01 April 2022 till 31 March 2023

ICARD Coordinator:
Dr. Hum Chand

Areas of research:

Extragalactic astronomy: Quasars absorption lines studies to probe the evolution of high-z proto-galaxy, cosmology using Lyman-alpha forest, cosmological variation of fundamental constants using high-resolution AGN spectroscopy, quasars outflow, AGN variability, AGN black hole mass estimations, multi-wavelength study of AGNs. Neutrino Astrophysics. Dark matter. Quantum Gravity.

Research work:

Our research group consisting of seven research scholars are engaged in studying the various aspects of the central engine of Active Galactic Nuclei (AGN). For this extensive archival multiwavelength data

has been also used by employing various observation features such as: the variability on diverse scales, modeling of Spectral Energy distribution (SED) of AGNs etc. We also have an active research group in Neutrino Astrophysics especially working on the solar neutrino problem.

List of publications using ICARD facilities

1. Evidence of underdeveloped torus and broad-line region of weak emission line quasars based on their spectral energy distribution Ritish Kumar, and **Hum Chand,** and Ravi Joshi,, 2023, MNRAS, 519, 3656K

2. The transience and persistence of high optical polarization state in beamed radio quasars Krishan Chand, and Gopal-Krishna and Amitesh Omar, and **Hum Chand**, and Bisht, P.~S., 2023, PASA, 40, 6C

3. Intranight optical variability of low-mass active galactic nuclei: a pointer to blazar-like activity; Gopal-Krishna , Krishan Chand; **Hum Chand**, Vibhore Negi, Sapna Mishra, S. Britzen, P. S. Bisht, 2023, MNRAS, 518L, 13G

4. "Muon (g-2) in U(1) LL Scotogenic Model Extended with Vector like Fermion" Simran Arora, Monal Kashav, Surender Verma, **B.C. Chauhan**, , Physica Scripta, Volume 98, Issue 2, id.025304, 12 pp, February 2023, 10.1088/1402-4896/acb32b https://arxiv.org/abs/2206.12828.

5. "Muon (g-2) and W-boson mass Anomaly in a Model Based on Z4 Symmetry with Vector like Fermion" Simran Arora, Monal Kashav, Surender Verma, **B.C. Chauhan**,, Progress of Theoretical and Experimental Physics, Volume 2022, November 2022, 113B06, https://doi.org/10.1093/ptep/ptac14.

Online course on Astronomy and Astrophysics:

The IUCAA Centre for Astronomy Research and Development (ICARD) at Central University of Himachal Pradesh, and the Astronomy Centre for Educators, IUCAA, has started an online introductory course on astronomy and astrophysics. This is for faculty members of higher educational institutions, with an emphasis on those from the Shivalik region. About 50 teachers from various colleges and Universities were selected for this online course. The course started on 22 March 2023 and lectures are held every week 6:30PM on Wednesday & Saturday untill May 31, 2023.

Any outreach programmes, including public lectures/sky watch arranged by ICARD, etc:

Our Master and research degree students also take part in outreach activities under the department club namely Chandra-STAR (Science Technology & Astronomy Realization) club (e.g https://chandrastarclub.github.io/). The activities include arranging lectures (online/offline) and sky show for general public and school/college students, with a few glimpses as below.

The sky-watching team during national Science day celebration in the department of Physics and Astronomical Science.

Prof. Dipankar Banerjeedelivering the online lecture on "Variability of our nearest star: The SUN" for our university students.

Prof. H. Chand delivering lecture on "From Atom to Cosmos" for degree college Dharamshala students.

ICARD, Physics Department, North Bengal University, Siliguri: Activities from 01 April 2022 till 31 March 2023

Coordinator:
Dr. Bikash Chandra Paul

Research Area:

- Relativistic Astrophysics,
- Cosmology,
- Compact Objects,
- DATA analysis of X-ray Sources,
- Non-linear Dynamics

DATA Centre Activities:

Research Scholars are engaged to Analyze X-ray Data of NASA to investigate Different X-ray emmiting Pulsars. At present four Research Scholars are engaged in doing research using the facilities of the ICARD DATA Centre. It is proposed to use ASTROSAT-data from IUCAA soon.

List of Seminars/Workshops/Schools organized:

ICARD organized the following webinar during pandemic

1. National Seminar on General Relativity and Astronomy (November 21, 2022)

1. A one-day National Seminar on General Relativity and Astronomy organized by the IUCAA Centre of Astronomy Research and Development (ICARD) at Physics Department, North Bengal University (NBU) on Nov. 21, 2022. Eminent Relativist and Astronomers delivered invited talks, N. Dadhich "Fundamental forces and their dynamics", S. V. Dhurandhar "Ripples in Space-time"and A. N. Ramaprakash "Probing the 3D structure of galactic dust and magnetic field" from IUCAA, Pune. A. Bhadra "A pursuit of the origin of Sagan Effect" from HECRC, NBU. The seminar was dedicated in the memory of Late Thanu Padmanabhan (Paddy). There were 95 students including research scholars and faculties from neighbouring collegesand university who actively participated the seminar. A brief introduction of the ICARD at NBU is introduced to the gathering by Dr. B. C. Paul, Coordinator of ICARD, NBU. Prof. Om Prakash Misra, Vice-Chancellor, North Bengal University welcome the distinguished scientists guests from IUCAA, Pune followed by a short description of IUCAA-NBU joint Programs by Profs. Naresh Dadhich and S. V. Dhurandhar at the inaugural talk.

2. Invited talk by B. C. Paul, "Cosmology : Present status" Exploring the Cosmos at HECRC, NBU on Feb. 15, 2023.

3. Outreach Program : " Black Holes: Are they Real" at Surya Sen Mahavidyalaya, Siliguri by B. C. Paul on Feb 15, 2023 (K.C.P.M.S.H.) for undergraduate students.

Publications by using ICARD facilities:

1. **B. C. Paul**, B. C. Roy, A. Saha, Bianchi-I anisotropic universe with Barrow holographic dark energy, Euro. Phy. Journal C 82, 1-7 (2022).

2. A. Saha, A. Chanda, S. Dey, S. Ghose, **B. C. Paul,** R\'enyi Holographic Dark Energy Models In multidimensional Universe, IJGMMP, 19 2250043 (2022).

3. R. Deb, P. Mandal**, B. C. Paul,** Wormholes in f(R, T) – gravity with density dependent B parameter in SQM, Euro Physics J Plus, 137 481 (2022).

4. **B. C. Paul**, S. D. Maharaj, A. Beesham, Reconstruction of modified

Gauss–Bonnet gravity for emergent universe- Reconstruction of modified Gauss–Bonnet gravity for emergent universe. Int. Journal of Modern Physics D**,** 2250045 (2022)

5. B. C. Paul, A Chanda, S Maharaj, A Beesham, Late time cosmology in f(R,G) gravity with interacting fluids, **C**lass. Quantum Grav. 39, 065006 (2022).

6. R. Sengupta, **B. C. Paul** and P. Paul - Skyrme Fluid in Anisotropic Universe, Pramana, J. of Physics 96, 114 (2022).

7. B. C. Paul. Shyam Das, Ranjan Sharma, Anisotropic Compact Objects with colour-flavour-locked equation of state in Finch-Skea geometry, Euro Phys. J. Plus 137, 525 (2022).

8. A. Chanda, **B. C. Paul**, Evolution of Primordial Black Holes in f(Q) gravity with non-linear equation of state, Euro. Phys.l Journal C 82**,** 616 (2022).

9. Bibhash Das, S. Dey, S. Das, **B. C. Paul,** Anisotropic Compact Objects with Finch-Skea geometry in EGB gravity, Euro. Phys. Journal C 82, 519 (2022).

10. Ruchi Tamang, M. Ghising, M. Tobrej, Binay Rai, **B. C. Paul,** Spectral and Timing analysis of Be/X-ray Binary EXO 2030+375 during its giant 2021 outburst, Mon. Not. Roy. Astron. Soc. (MNRAS) 515, 5407-5415 (2022).

11. M. Ghising, Ruchi Tamang, M. Tobrej, Binay Rai, **B. C. Paul,** Spectral & Timing Analysis of BeXRB eRASSU J050810.4-660653 recently discovered in the Large Magellanic Cloud (LMC), Mon. Not. Roy. Astron. Soc. (MNRAS) 518**,** 893-899 (2023).

12. M. Ghising, Md. Tobrej, B. Rai, R. Tamang, **B. C. Paul**- NuSTAR observation of X-ray pulsar 1E 1145.1- 6141. Mon. Not. Roy. Astron. Soc. (MNRAS) 517, 4132-4137 (2022)

13. B. Rai, M. Ghising, R. Tamang, Md. Tobrej and **B. C. Paul -** Spectral and Timing properties of the recently discovered Be/X-ray pulsar eRASSUJ 052914.9-662446, Mon. Not. Roy. Astron. Soc. (MNRAS) 517**,** 4092-4097 (2022).

14. Mohammed Tobrej Manoj Ghising, Binay Rai, Ruchi Tamang, **Bikash Chandra Paul,** X-ray observations of 1A 1744-361 during its 2022 outburst, Mon. Not. Roy. Astron. Soc. (MNRAS) MN-22-3402-MJ (2022).

15. M. Ghising, R. Tamang, Md Tobrej, B. Rai, **B. C. Paul** - Super-critical accretion in BeXRB SXP 15.3, Mon. Not. Roy. Astron. Soc. (MNRAS) 520**,** 3396-3404 (2023)

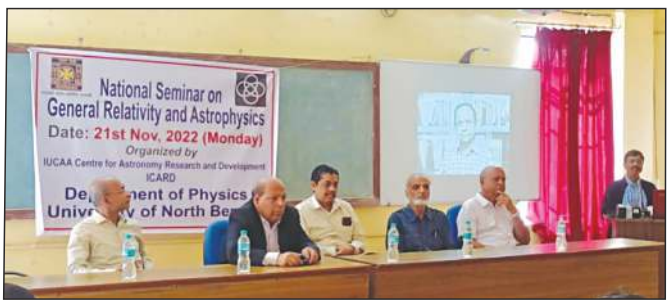
16. A. Chanda, A. Halder, A. S. Majumdar, **B. C. Paul,** Late time cosmology in $f(R,\mathcal{G})$ gravity with exponential interactions, Euro. Phys. Journal C 83, 23 (2023).

17. R. Sengupta, B C Paul, M. Kalam, Lorentzian wormholes in an emergent universe, Class. Quantum Grav. 40, 095009 (2023).

18. B Rai, B Paul, M Tobrej, M Ghising, R Tamang, **B. C. Paul,** Spectral properties of the BE/X-ray pulsar 2S 1553-542 during Type II outbursts, *arXiv:2211.09082* (2022), **J.** Astrophysics & Astronomy *(accepted)* (2023)

Md. Tobrej, Bi. Rai, M. Ghising, R. Tamang, **Bikash Chandra Paul**, A high-mass X-ray binary pulsar 4U 1907+09 with multiple absorption-line features in the spectrum. Mon. Not. Roy. Astron. Soc. (MNRAS) 518, 4861-4869 (2023)

Photograph of the Seminar



ICARD, Department of Physics, Tezpur University, Tezpur: Activities from 01 April 2022 till 31 March 2023

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 have been involved in collaborative research work with IUCAA faculty members since long time. Since the inception of ICARD at Tezpur University, four students, Dr Gautam Saikia, Dr Aishawnnya Sharma, Dr. Pranjupriya Goswami and Dr. Rukaiya Khatoon have received their PhD degrees. All of them worked in collaboration with IUCAA faculty members.

There are ongoing research work on Galaxy morphology, Active Galactic Nuclei and Solar Astronomy in active collaboration with IUCAA faculty members Prof. Ranjeev Misra, Prof. Kanak Saha and Prof. Durgesh Tripathi. Group members of Prof. Gazi Ameen Ahmed and Dr Rupjyoti Gogoi are involved in these collaborative research works. The students presently involved are Anshuman Borgohain, Janmejoy Sarkar and Hritwik Bora.

Moreover, Dr Biplob Sarkar from Department of Applied Sciences and his PhD students Sree Bhattacherjee and Arbind Pradhan are also working in collaboration with Prof. Ranjeev Misra, IUCAA, Pune in the field of X-ray Astronomy. The Department of Applied Sciences was established under the School of Engineering, Tezpur University in 2019.

List of any workshops/schools organized by ICARD:

(I) Talks organized:

(i) Talk on "Our dusty view of the Universe" on 17th November, 2022 by Dr. Shalima Puthiyaveettil, Manipal Centre for Natural Sciences, MAHE, Manipal, Karnataka.

(ii) Talk on "Peeking into various astrophysical phenomena using cosmic clocks" on 12th December, 2022 by Jaikhomba Singha, IIT Roorkee. He is an alumnus of Tezpur University.

(ii) School Outreach:

On February 3, 2023, we organized a school outreach programme at nearby Fakharuddin Ali Ahmed High School. The participants were from 8th to 10th standard. Our student volunteers tried to explain some basic astronomical ideas to give the students a preliminary flavor of the field of astronomy. Also, there were interactive sessions with the school students to address their queries on Astronomy as a subject and as a future career.

(iii) Events organized in collaboration with ICARD, Tezpur University:

(I) 4th IUCAA sponsored Workshop on Astronomical Data Analysis (WADA 2022):

WADA 2022 was organized by the Department of Physics, Jagannath Barooah College, Jorhat, Assam, during May 12-14, 2022. There were talks by IUCAA associates from Tezpur University. There were special talks by faculty members of different colleges of Assam, who worked in collaboration with IUCAA faculty members during their PhD at Tezpur University. There were hands on sessions on astronomical data analysis conducted by Research Scholars of Tezpur University.

(ii) 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 8th edition of NEMA was organized by Department of Physics, Manipur University during 21-23 November, 2022. ICARD, Tezpur University helped them in preparing the proposal and in conducting the event. 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 in blended mode (online+offline).

List of publications by using ICARD facilities (2022-23):

Members of ICARD, Tezpur University have published the following journal papers as collaborative efforts with IUCAA faculty members:

(i) "Temporal and spectral study of PKS⊗0208−512 during the 2019–2020 flare", Rukaiya Khatoon, Raj Prince, Zahir Shah, Sunder Sahayanathan, **Rupjyoti Gogoi**, Monthly Notices of the Royal Astronomical Society, volume 513, issue 1, June 2022, pages 611–623, published on 25 April 2022.

(ii) "Extended far-ultraviolet emission in distant dwarf galaxies", Anshuman

Borgohain, Kanak Saha, Bruce Elmegreen, **Rupjyoti Gogoi**, Francoise Combes & Shyam N. Tandon, Nature, volume 607, pages 459–462, published on 20 July 2022.

(iii) "Correlations between X-ray spectral parameters of Mkn⊗421 using long-term Swift–XRT data", Rukaiya Khatoon, Zahir Shah, Jyotishree Hota, Ranjeev Misra, **Rupjyoti Gogoi**, **Ananta C Pradhan**, Monthly Notices of the Royal Astronomical Society, volume 515, issue 3, pages 3749–3759, published on 25 July 2022.

(iv) "Simultaneous X-ray/UV Observations of Ultraluminous X-ray Source Holmberg II X-1 with Indian Space Mission Astrosat", A. Vinokurov, K. Atapin, O. P. Bordoloi, A. Sarkisyan, U. Kashyap, M. Chakraborty, P. T. Rahna, A. Kostenkov, Y. Solovyeva, S. Fabrika, M. Safonova, **R. Gogoi**, F. Sutaria & J. Murthy, Astrophysical Bulletin, volume 77, pages 231–245, published on 30 September 2022.

Image 1: School Outreach Programme at Fakharuddin Ali Ahmed High School.

Image 2: IUCAA sponsored workshop at J.B. College, Jorhat

ICARD, Newman College, Thodupuzha, Kerala: Activities from 01 April 2022 till 31 March 2023

Coordinator:
Dr. Joe Jacob

Areas of research:

Radio Astronomy, X-ray Astronomy

Research work done at ICARD:

Research scholar Mrs.Neha P. R, analysed the X-ray data of Mrk 335 from five swift XRT observations obtained from 2007 to 2009.The spectral studies show both spectral and flux variability of the source. She also studied the AGN Ark564, for which ninety-nine observations of X-ray data during the same period was consolidated. Coorelation graphs were plotted between different parametres obtained from the data analysis.

Mrs. Aparna Raj, cross-matched the various radio catalogues available to identify the restarted radio sources in the sky. She used the spectral curvature technique for this and could find many hitherto unknown sources. Fifteen of the sources identified with peculiar radio properties have been observed with GMRT and further investigations are being done.

Outreach programmes, including public lectures/sky watch arranged by ICARD.

1. Seminar on Radio Astronomy and Demonstration of Horn Antenna, June 9, 2022

A one-day workshop on 'Radio astronomy' and the demonstration of the Radio Horn antenna was conducted on 9th June 2022 in the Malekkudy Hall of the college. Ms. Vijayalakshmi V, an alumnus of the college was the resource person. The workshop which was co-ordinated by Dr. Joe Jacob and Dr. Subin Jose was arranged on the terrace of the Jubilee building, where the antenna is placed. Students and the public attended the programme

fig 1: Ms.Vijayalakshmi V, explaining the working of the horn antenna

2. Seminar on James Webb space Telescope for school Students- June 25, 2022

A seminar on 'James Webb space Telescope' was conducted on 25th June 2022 at 9 am. Dr. Joe Jacob, coordinator of ICARD and former Head of the Department of Physics of Newman College delivered the talk. The session detailed the revolutionary changes in the understanding of the Universe expected to be unravelled by the James Web Telescope. Forty school students from the region participated in the Seminar.

3. Celebration of Moon Day – July 27, 2022

Department of Physics, Newman College Thodupuzha commemorated 'International Moon Day 2022' on 27th July 2022 at the auspices of ICARD. As a curtain-raiser for the celebrations, an inter-departmental Quiz competition was conducted on 27th July, at 10.30 am. Twenty-nine teams from various departments participated in the preliminary round and four teams were selected for the final round. The meeting which followed was presided over by Dr. Saju Abraham and felicitated by Dr. Joe Jacob. A talk on "Citizen Science Program: Research at Home" was delivered by Ms. Vijayalakshmi V., a former student. Prizes and certificates were distributed to the winners of the Quiz competition. The event was attended by nearly a hundred undergraduate students.

fig 2: (a) Dr. Joe Jacob falicitating the moon day celebrations meeting (b) The poster for the moon day celebrations

4. Skywatch programme on September 28, 2022 and February 7, 2023

(a) Jupiter Observation:

A skywatch programme was conducted at Newman College under the auspices of ICARD to watch the event of the closest approach of planet Jupiter to earth on the 28th of September 2022, using the Celestron 11" telescope.

(b) Comet observation

Another skywatch programme for observing the comet ZTF was conducted on the 7th of February

Mr. Sudheesh Thankappan, and Mr. Krishnaprasad K. R, Research scholars of the Department were the resource persons and Dr. Indu Sebastian and Dr. Riya Sebastian were the coordinators of the program. The programme was attended by the students from the college and the neighbouring schools and also by the public. It motivated many questions and was indeed an enlightening experience for the participants.

5. Seminar on Safe Observation of Solar Eclipse-October 25, 2022

To abolish the myths and superstitions regarding solar eclipses among the public, the Department of Physics organized a seminar on 25 th of October 2022. Dr. Beena Mary John delivered a talk detailing the prevalent myths and superstitions on eclipse and the scientific counterarguments against it. She also explained how to safely observe the eclipse with demonstrations of the various methods.

6. Physics Camp for School Students- February 24-25, 2023

A Two-day Physics camp, 'Spectra' was conducted for High School and Higher Secondary school students during 24-25 February 2023. Sixty seven students from nine schools from the region participated in the programme. The sessions were handled by experts in various fields and included experimental demonstrations, group activities and games based on Physics. Dr Joe Jacob (Retd. Professor and ICARD coordinator) inaugurated the camp. Fr. Benson N Antony, Bursar of Newman college, presided over the function.

fig 3: (a) Dr. Ajith Thomas demonstrating physics experiments (b) Student participants explaining the poster which they made

7. National Science Day celebration- February 27, 28. March 1, 2023

National science day celebrations were held at the college under the auspices of ICARD on February 27, 28th and 1 st of March. Seminars, Quizzes and Essay competitions on science topics were conducted for the college students and a Science poster competition was held for the school students. Prizes were distributed to the winners in a meeting presided over by Dr. Saju Abraham Vice-Principal and attended by Dr. Joe Jacob, co-ordinator of ICARD.

School of Studies in Physics and Astrophysics Pt. Ravishankar Shukla University, Raipur - 492010

Coordinator:
N. K. Chakradhari

1. Areas of research

Supernovae, X-ray Binaries, GRBs and Galaxies

2. Research work

Spectral and timing analysis of X-ray Binaries is being carried out by N.K. Chakradhari, Pravat Dangal (Thesis work) in collaboration with Ranjeev Mishra (IUCAA, Pune). UV-optical photometric and spectroscopic study of supernovae is being carried out by N.K. Chakradhari, Shritika Tiwari (Thesis work) and Kripa Ram Sahu (Thesis work) in collaboration with G.C. Anupama and D.K. Sahu (IIA, Bengaluru). Study of early-type/lenticular galaxies were carried out by Mahendra Kumar Verma (Thesis submitted), Amit Kumar Tamrakar (Thesis submitted), Laxmikant Chaware, S.K. Pandey and in collaboration with S. Barwey (IIA Bengaluru). Ms. Bharti Arora was awarded PhD on Massive O-type and WR stars under J. C. Pandey (ARIES, Nainital) and N.K. Chakradhari (co-supervisor). Ankur Ghosh has submitted his thesis on Study of GRBs, under Amitesh Omar, Kuntal Misra (ARIES, Nainital) and N.K. Chakradhari (co-supervisor).

3. Workshop

STAR 2022

IUCAA supported a four-day international workshop on Science and Technology in Astronomy Research (STAR 2022) was organized from 15 to 18 October 2022. Ranjeev Misra and N.K. Chakradhari worked as convener. There were 21 lectures of scientists and researchers. The participants got detailed information about the Universe, the development of astronomy, Giant Telescopes, Space Observatories, Supernova Explosion, the motion of

celestial bodies, X-ray binaries, Black Holes, Gravitational waves, Dark Energy, Space Weather, Solar Physics, Extra-Solar Planets, Galaxies, Cosmology, and Python. They were also informed about their career and opportunities in astronomy. A group of students demonstrated the use of python in Astronomy by taking examples such as PL relation and distance measurements, use of HR diagram in main-sequence fit method, Hubble's expansion law and age of the Universe, Kepler's law and Planetary motion etc. Some students displayed their knowledge and art through Rangoli and painting competitions. Students who outperformed were rewarded. Skywatching program was organized in the evening. Besides the workshop participants, many nearby families, including kids, joined sky watching enthusiastically. It was a matter of curiosity for some of the participants to see the planet Saturn and Jupiter, for the first time, the response was overwhelming. There were 80 offline participants and 135 online participants.

NSSEMA 2023

Prof. Dipankar Banerjee (Director, ARIES Nainital and President ASI) gave an important lecture on Solar Physics and Aditya-L1 mission. Prof. G. C. Anupama (Visiting Professor, Former Dean & Senior Professor, IIA Bengaluru) gave an important lecture on thermonuclear supernovae (16-18 March 2023).

TARE

We have initiated a TARE (Training in Astronomy Research and Education) programme in nearby colleges. A one-day workshop TARE-2022 was organized at Govt. College Dharsiwa, Raipur on 28 November 2022. Telescope demonstration and Sky watching was held in the evening.

4. List of publications

1. Type Ia supernovae SN 2013bz, PSN J0910+5003 and ASASSN-16ex: similar to 09dc-like? Tiwari S., Chakradhari N. K., Sahu D. K., Anupama G.C., Kumar B., and Sahu K.R., 2023, MNRAS, 521, 5207.
2. Search for merger ejecta emission from late time radio observations of short GRBs using GMRT, Ghosh Ankur, Vaishnava C. S., Resmi L., Misra Kuntal, Arun K. G., Omar Amitesh, Chakradhari N. K., 2023, MNRAS, arXiv: 2207.10001.
3. Can the violent merger of white dwarfs explain the slowest declining Type Ia supernova SN 2011aa? Dutta Anirban, Anupama G C, Chakradhari N K, Sahu D K, 2022, ApJL, 938, 22.
4. Modeling the late-time merger ejecta emission in short gamma ray bursts, Ankur Ghosh, Kuntal Misra, S. V. Cherukuri, L. Resmi, K. G. Arun, Amitesh Omar, Dimple, N. K. Chakradhari, 2022, Journal of Astrophysics & Astronomy, 43, 66.
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6. **Luminous type Ia Supernova SN 2013bz, Shrutika Tiwari, N. K. Chakradhari, D.K. Sahu, G. C. Anupama and K. R. Sahu. Poster, ASI-2023, IIT Indore, 1-5 March 2023.**
7. Photometric and spectroscopic studies of type Ia supernova SN 2013bz, Shrutika Tiwari, N. K. Chakradhari, D. K. Sahu, G. C. Anupama, K. R. Sahu. Poster, Young Astronomers' Meet 2022, ARIES Nainital, 9-13 November 2022.
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5. Outreach programmes

Talks/public lectures

(I) 27 Feb 2023: The amazing sky, at Govt. Rajiv Lochan P.G. College, Rajim (ii) 23 Feb 2023: The world of Stars, at Govt. D.B. Girls P.G. College, Raipur (iii) 17 Feb 2023: Global Science for Global Wellbeing - The Science of Stars, at SPCA College, Nawapara-Rajim (iv) 28 November 2022: Understanding the Sky, Govt. College Dharsiwa, Raipur (v) 15-18 October 2022: The legacy of Physics & Astrophysics at Pt. R.S. University, Raipur, STAR-2022 International workshop (vi) 02 May 2022: Explosions in the cosmos: Supernovae, at Physics Department, Kalinga University, Raipur (vii) 16-18 March 2023: Time Resolved Spectral Analysis of an eclipsing High Mass X-ray Binary 4U 1118-60 over a full binary orbit with ASTROSAT (by Pravat Dangal) at NSSEMA-2023 PRSU Raipur (viii) 15-18 October 2022: Template fitting on type Ia supernova light curves (by Shrutika Tiwari) at STAR-2022 PRSU Raipur.

Sky watching programmes

(I) Govt. P.G. College, Rajim (27 Feb 2023)

(ii) SPCA College, Nawapara-Rajim (17 Feb 2023)

(iii) NIT, Raipur on 02 and 03 Feb 2023

(iv) Partial Lunar Eclipse on 08 November 2022

(v) Partial Solar Eclipse on 25 October 2022

(vi) SoS in Physics & Astrophysics on 16 April 2022.

PUBLICATIONS BY IUCAA MEMBERS

Journals:

1. **Debabrata Adak**, Aparajita Sen, Soumen Basak, Jacques Delabrouille, Tuhin Ghosh, Aditya Rotti, Ginés Martínez-Solaeche, **Tarun Souradeep** (2022) *B-mode forecast of CMB-Bhārat*, MNRAS, **514**, 3002.

2. S. Mondal, **T. P. Adhikari**, K. Hryniewicz, C. S. Stalin and A. Pandey (2022) *Variable mass accretion and failed wind explain changing-look phenomena in NGC 1365*, A&A, **662**, A77.

3. **Deepali Agarwal,** Jishnu Suresh, Vuk Mandic, Andrew Matas, and Tania Regimbau (2022) *Targeted search for the stochastic gravitational-wave background from the galactic millisecond pulsar population*, PhRvD, **106**, 043019.

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Proceedings

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2. **B. G. Dutta** & S. K. Chakrabarti (2022) *Time Lag Properties In Black Hole Binaries: Implication On ACCRETION DISK GEOMETRY*'' in 44th COSPAR Scientific Assembly. Held 16-24 July, 2022. Online at https://www.cosparathens2022.org/

3. **B. G. Dutta**, P. Nandi, A. Chatterjee & S. Mondal (2022) *A Similar Accretion Disk Dynamics In Bare-Type Agn Ark 120 And Galactic Black Hole Binaries*, Online at https://www.cosparathens2022.org/

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6. **Sushant G. Ghosh** and Rahul Kumar Walia (2023) *Shadows of Kerr-like black holes in 4D Einstein–Gauss–Bonnet gravity and constraints from EHT observations*, Proceeedings of the MG16 Meeting on General Relativity, Remo Ruffini, Gregory Vereshchagin (eds.) (World Scientific, 2023) pp. 1069-1083 doi:10.1142/9789811269776_0084

7. L. Giridharan, N. T. Thomas, **S. B. Gudennavar** and S. G. Bubbly (2023) *Spectro-timing properties of GX 13+1 using AstroSat observations,* National Conference on REcent Trends in the Study of Compact Objects (RETCO-V): Theory and Observation

to be held during April 3 - 5, 2023 at Kodaikanal Solar Observatory, Tamil Nadu, India.

8. N. T. Thomas, T. S. Sidharth Nath, **S. B. Gudennavar** and S G Bubbly (2023) *Unveiling spectral properties of 4U 1820-30 using AstroSat, National Conference on REcent Trends in the Study of Compact Objects (RETCO-V): Theory and Observation to be* held during April 3 - 5, 2023 at Kodaikanal Solar Observatory, Tamil Nadu, India.

9. N. T. Thomas, M. Varun, Navya T. Jacob, **S. B. Gudennavar** and S. G. Bubbly (2023) *Spectral studies of 4U 1636-536 using AstroSat*, National Conference on REcent Trends in the Study of Compact Objects (RETCO-V): Theory and Observation to be held during April 3 - 5, 2023 at Kodaikanal Solar Observatory, Tamil Nadu, India.

10. **S. B. Gudennavar**, N. T. Thomas and S. G. Bubbly (2023) *Spectro-temporal studies of GX 9+1 using AstroSat,* National Conference on REcent Trends in the Study of Compact Objects (RETCO-V): Theory and Observation held during April 3 - 5, 2023 at Kodaikanal Solar Observatory, Tamil Nadu, India.

11. N. T. Thomas, **S. B. Gudennavar** and S. G. Bubbly, *Unravelling properties of GX 3+1 through AstroSat observations,* National Conference on REcent Trends in the Study of Compact Objects (RETCO-V): Theory and Observation held during April 3 - 5, 2023 at Kodaikanal Solar Observatory, Tamil Nadu, India.

12. N. T. Thomas, Khushi Jirawala, Vaishnavi Nakra, **S. B. Gudennavar** and S. G. Bubbly, *Spectral properties of XTE J1701-462 using AstroSat,* National Conference on REcent Trends in the Study of Compact Objects (RETCO-V): Theory and Observation held during April 3 - 5, 2023 at Kodaikanal Solar Observatory, Tamil Nadu, India.

13. N. T. Thomas, **S. B. Gudennavar**, S. G. Bubbly, Unravelling properties of GX 3+1 through AstroSat observations, Proceedings of the Young Astronomers Meet 2022 held during November 9 - 13, 2022 at ARIES, Nainital, India.

14. M. V. Sazhin, M. Safonova, V. N. Sementsov, **P. Hasan** and N. Hasan (2022) *Using Artsimovich Railgun (Relsotron) for Payloads Delivery from the Moon*, 53rd Lunar and Planetary Science Conference, March 7–11, 2022, Houston.

Circular and Telegrams

1. Jaiverdhan Chauhan, **Priya Bharali**, Manoj Mandal, Paul Draghis, Sabyasachi Pal, Anne Lohfink, Andrea Sanna (2022) *Detection of X-ray reflection in MAXI J1816-195 with the NuSTAR, The Astronomer*'s Telegram, Published in June, 2022.

Awards and Honors

Aru Beri

International Women Young Researcher Award Winner Venus International Women Awards (VIWA)
Newton International Fellowship Alumni in 2022.

Naseer Iqbal bhat

Received INSA Teacher award in Astrophysics / Physics 2021 from INSA Indian National Science Academy New Delhi on 15th December 2022 at Vishakapatnam. The award carries a cash reward of Rs/ 50, 000, Citation and book grant of Rs 25, 000.

Received best Science Communicator Award-2022 by J and K Science Communicators Network in September 2022.

Mayukh R. Gangopadhyay

Associate, Indian Academy of Sciences, Bengaluru, 2022

Sushant Ghosh

Four papers listed below published in 2020 received IOP Publishing's top cited award 2022

1. Black Hole Parameter Estimation from Its Shadow in Astrophysical Journal: https://iopscience.iop.org/article/10.3847/1538-4357/ab77b0. - Rahul Kumar Walia and Sushant G. Ghosh – 83 citations

2. Rotating black holes in 4D Einstein-Gauss-Bonnet gravity and its shadow in the Journal of Cosmology and Astroparticle Physics: https://iopscience.iop.org/.../10.1088/1475-7516/2020/07/053 - Rahul Kumar Walia and Sushant G. Ghosh – 151 citations

3. Gravitational lensing by black holes in the 4D Einstein-Gauss-Bonnet gravity in the Journal of Cosmology and Astroparticle Physics: https://iopscience.iop.org/.../10.1088/1475-7516/2020/09/030 - Shafqat Ul Islam, Rahul Kumar, and Sushant G. Ghosh - 119 citations

4. Generating black holes in 4D Einstein-Gauss-Bonnet gravity' in Classical and Quantum Gravity: https://iopscience.iop.org/article/10.1088/1361-6382/abc134 Sushant G. Ghosh and Rahul Kumar - 77 citations.

The citations record of the Web of Science have listed these papers as the most cited articles from India published across the entire IOP Publishing journal portfolio in the period 2019 to 2021. The publications feature in the top 1% of the most cited papers in astronomy and astrophysics.

Kenath Arun

Honourable mention (2022) Awards for Essays on Gravitation, Gravity Research Foundation, Massachusetts, USA for the paper *From maximum force to the field equations of general relativity and implications*

A. Pradhan

Included in the list of the top 2% world scientists in Nuclear and Particle Physics by the Mendeley Scientific Organization (Stanford University, USA).

Awarded the 2022 Outstanding Reviewer Certificate for the Canadian Journal of Physics.

Recevied the Aishwarya Memorial Award for Excellence in Research by the Shanti Education Research Foundation, India on February 22, 2023.

Book:

Suresh Chandra

Beauty of our SOLAR SYSTEM by Suresh Chandra, Mohit K. Sharma and Arvind K. Sharma Ayan Prakashan, New Delhi (2022) (ISBN: 978-93-94221-61-1)

A Textbook on the Knowledge System of Bharata, Garuda Prakashan, New Delhi 2023.

A Report: Shodh Sansthan ke Vividh Ayam-2 (on the yearlong activities of Neri Shodh Sansthan) 2022 as Chief-Editor.

Priya Hasan

Astronomy Olympiads: Problems with Solutions by Prof Vladimir G. Surdin (Author), Margarita Safonova (Translator), Priya Hasan (Translator), S. N. Hasan (Translator) OrangeBooks Publication; 1st edition (6 April 2023), **ISBN-10** : 9356216711, **ISBN-13** : 978-9356216716

Chetana Jain

Computing in Scilab, Cambridge University Press. **ISBN-13:** 978-1009214193

Kenath Arun

A Guide to Black Holes, ed. Kenath Arun, Nova Science Publishers, New York, 2023 (ISBN: 9798886971637)

P. R. Prince

Programming with Microprocessors, 8085 and 8086, Owl Books, Trivandrum August 2022, ISBN: 978-93-85666-16-2

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-3366**
Dated : 27.01.1989

Balance Sheet As At : 31.03.2023

FUNDS & LIABILITIES	Schedule no	Rs.	Current year 01.04.2022 to 31.03.2023 Rs	Previous year 01.04.2021 to 31.03.2022 Rs
Trusts Funds or Corpus :-	6			
Balance as per last Balance Sheet		2,20,19,497		
Adjustment during the year (give details)		25,75,916		
Schedule No. 6			2,45,95,413	2,20,19,497
Other Earmarked Funds :-	7			
(Created under the provisions of the trust deed or scheme or out of the income)			11,44,03,826	10,10,14,244
Balance as per last Balance Sheet		**Opening Balance**		
Grant in Aid - 2 MIR (CAPITAL)			11,90,80,000	11,90,80,000
Grant in Aid BUILDING			11,97,49,000	11,97,49,000
Capital Grant to the Extent of Depreciation		(1,62,47,82,321)		
Additions during the year		(15,72,47,589)	(1,78,20,29,910)	(1,62,47,82,321)
Grant in Aid General (Capital) from UGC		2,42,07,24,799		
Additions during the year		15,00,00,000		
Add: Interest		5,32,074		
Less : Subtraction/reversal		0		
Schedule No. 7			2,57,12,56,873	2,42,07,24,799
Any Other Fund - Project Grants	8			
Schedule No. 8			36,63,77,901	34,99,08,648
Loans (Secured or Unsecured) :-				
From Trustees			NIL	
From Others			NIL	
Liabilities :-	10 & 10 A			
For Expenses and other liabilities			33,10,67,752	36,51,35,285
For Projects and Other Payables			9,03,36,338	10,49,55,146
For Rent & Other Deposits, duties and taxes			9,69,781	31,488
For Sundry Credit Balances			1,01,50,538	25,29,869
Schedule No. 10 &10 A				
Income and Expenditure Account :-	14			
Balance as per last Balance Sheet				
Less : Appropriation, if any				
Add : Deficit during the year				
Less Surplus				
Schedule No. 14			NIL	NIL
Total Rs.....			1,96,59,57,512	1,98,03,65,655

PROPERTY & ASSETS	Schedule no	Rs.	Current year 01.04.2022 to 31.03.2023 Rs	Previous year 01.04.2021 to 31.03.2022 Rs
Immovable Properties :- (At Cost)	11			
Balance as per last Balance Sheet		57,24,85,950		
Additions during the year		35,47,36,752		
Less : Sales /written off during the year		34,30,650		
Depreciation up to date		15,30,39,212		
Schedule No. 11			67,07,52,839	58,67,44,476
Investments :-	12			
Note : The market value of the above investment is **Rs.**				
Schedule No. 12			63,91,85,527	75,62,25,819
Furniture & Fixtures :-	11		2,09,48,145	2,45,50,696
Balance as per last Balance Sheet		2,45,50,696		
Additions during the year		5,11,467		
Less : Sales /written off during the year		2,38,641		
Depreciation up to date		42,08,377		
Loans (Secured or Unsecured) : Good / doubtful			NIL	NIL
Loans Scholarships			NIL	1,36,67,388
Other Loans				
Advances :-	13			
To Trustees			NIL	NIL
To Employees and other			1,12,70,286	
To Suppliers/Security Deposits/Prepaid Exp.			1,46,78,136	1,97,51,527
To Lawyers			NIL	NIL
To Project and Other Receivables			46,03,786	38,60,659
Schedule no. 13				
Income Outstanding :-				
Rent				
Interest				
Other Income				
Cash and Bank Balances :-	13			
(a) In Savings Account with HDFC				
In Fixed Deposit Account with				
(b) With the Trustee				
(c) With the Manager				
Schedule no. 13			17,89,25,321	6,43,68,702
Income and Expenditure Account :-	14			
Balance as per Balance Sheet		49,11,96,328		
Less : Appropriation, if any		(9,61,45,140)		
Add : Deficit as per Income and		3,05,42,582		
Less : Surplus Expenditure Account			42,55,93,470	49,11,96,328
Total Rs.....			1,96,59,57,512	1,98,03,65,655

As per our report of even date

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 AH JOSHI&CO.
Chartered Accountants
FRN: 112396W

For Inter-University Centre for Astronomy and Astrophysics

Place : Pune
Date : 31.05.2023

S.A. Joshi (Partner)
Membership No : 037772
UDIN

M.S. Sahasrabudhe
Admin. Officer (Accounts)

N.V. Abhyankar
(Sr. Admin. Officer)

Prof. R. Srianand
Director / Trustee

Chairperson/Trustee
Governing Board

matchstickds@gmail.com

IUCAA

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