

32nd
वार्षिक प्रतिवेदन
ANNUAL REPORT
2019 - 2020

IUCAA

अंतर - विश्वविद्यालय केंद्र : खगोलविज्ञान और खगोलभौतिकी

INTER - UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

Inter-University Centre for Astronomy and Astrophysics

(An Autonomous Institution of the University Grants Commission)



ANNUAL REPORT

(April 1, 2019 - March 31, 2020)

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Eclipse under the Bamboo

Image Credit and Copyright:
Somak Raychaudhury
(Inter-University Centre for Astronomy and Astrophysics)

Explanation:
Want to watch a solar eclipse safely? Try looking down instead of up, though you might discover you have a plethora of images to choose from. For example, during the Solar Eclipse on June 21, 2020, this confusing display appeared under a shady bamboo grove in IUCAA. Small gaps between close knit leaves on the tall plants effectively created a network of randomly placed pinholes. Each one projected a separate image of the eclipsed Sun.

The snapshot was taken close to the time of maximum eclipse in Pune when the Moon covered about 60 percent of the Sun's diameter. But an annular eclipse, the Moon in silhouette completely surrounded by a bright solar disk at maximum, could be seen along a narrow path where the Moon's dark shadow crossed central Africa, South Asia, and China.

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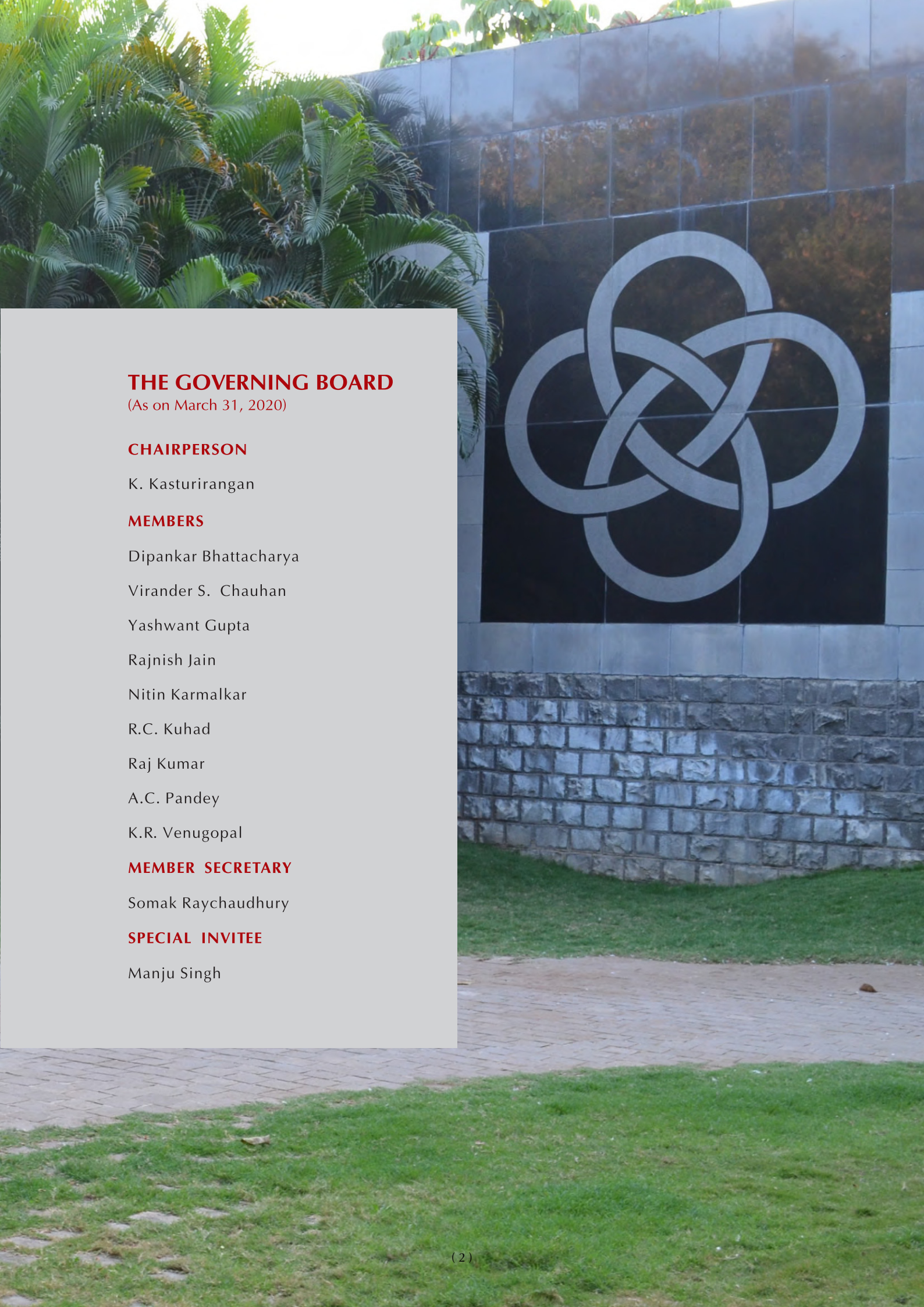
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149. Ranjan Sharma, Department of Physics, Cooch Behar Panchanan Barma University.
150. Alkendra Singh, Department of Physics, Institute of Science, Banaras Hindu University, Varanasi.
151. Gyan Prakash Singh, Department of Mathematics, Visvesvaraya National Institute of Technology, Nagpur.
152. Harinder Pal Singh, Department of Physics and Astrophysics, University of Delhi.
153. Heisnam Shanjit Singh, Department of Physics, Rajiv Gandhi University, Itanagar.
154. Monika Sinha, Department of Physics, IIT, Jodhpur.
155. Surendra Nadh Somala, Department of Civil Engineering, IIT, Hyderabad.
156. Vikram Soni, Centre for Theoretical Physics, Jamia Millia Islamia, New Delhi.
157. K. Sriram, Department of Astronomy, University College of Science, Osmania University, Hyderabad.
158. L. Sriramkumar, Department of Physics, IIT – Madras, Chennai.
159. Parijat Thakur, Department of Basic Sciences and Humanities, Guru Ghasidas Central University, Bilaspur.
160. Arun Varma Thampan, Department of Physics, St. Joseph's College, Bengaluru.
161. Sunil Kumar Tripathy, Department of Physics, Indira Gandhi Institute of Technology, Dhenkanal.
162. Pranjal Trivedi, Department of Physics, Sri Venkateswara College, Delhi.
163. Vinutha Tummala, Department of Applied Mathematics, Andhra University, Visakhapatnam.
164. Rashmi Uniyal, Department of Physics, Government Degree College, Narendranagar,
165. Sanil Unnikrishnan, Department of Physics, St. Stephen's College, Delhi.
166. Sudhaker Upadhyay Department of Physics, KLS College, Nawada.
167. Anisul Ain Usmani, Department of Physics, Aligarh Muslim University.
168. Nilkanth Dattatray Vagshette, Department of Physics and Electronics, Maharashtra Udaygiri Mahavidyalaya, Udgir.
169. Deepak Vaid, Department of Physics, NIT, Surathkal.
170. Bhargav Pradeep Vaidya, Discipline of Astronomy, Astrophysics and Space Engineering, IIT, Indore.
171. Murli Manohar Verma, Department of Physics, University of Lucknow.
172. Jaswant Kumar Yadav, Department of Physics, Central University of Haryana, Mahendergarh.
173. Lalthakimi Zadeng, Department of Physics, Mizoram University, Aizawl.

The Thirtieth batch (2019) of Visiting Associates, who were selected for a tenure of three years, beginning, August 1, 2019.


Sheelu Abraham


Aru Beri


Biju K. G.


Moon Moon Devi


Ankur Gogoi


Aruna Govada


Mamta Gulati


Rinku Jacob


Vinjanampaty Madhurima


Mubashir Hamid Mir


Aditya Mondal


Prince P. R.


Ramprasad Prajapati


Md. Anisur Rahaman


Biplob Sarkar


Tamal Sarkar


L.Sriram kumar


Nilkanth Vagshette


Lalthakimi Zadeng

Appointment of the following Visiting Associates of the Twenty-Seventh batch was extended for three years from August 2019:

G. Ambika, Tanwi Bandyopadhyay, Debbijoy Bhattacharya, Subenoy Chakraborty, Raghavendra Chaubey, Bhag Chand Chauhan, Himadri Sekhar Das, Abhirup Datta, Kanan Kumar Datta, Sukanta Deb, Gurudatta Gaur, Sushant G. Ghosh, Sutapa Ghosh, Rupjyoti Gogoi, Umananda Dev Goswami, Shivappa Bharamappa Gudennavar, K. P. Harikrishnan, K. Indulekha, Md. Mehedi Kalam, Sanjeev Kalita, Ram Kishor, Jaswant Kumar, Nagendra Kumar, Shiva Kumar Malapaka, Bivudutta Mishra, Barun Kumar Pal, Madhav K. Patil, Devraj Damaji Pawar, Anirudh Pradhan, S.R. Rajesh, Biplab Raychaudhuri, Anirban Saha, Sudipta Sarkar, Anjan Ananda Sen, Harinder Pal Singh, Surendra Nadh Somala, Anisul Ain Usmani, and Murli Manohar Verma.

ORGANIZATIONAL STRUCTURE OF ACADEMIC PROGRAMMES (As on March 31, 2020)



The Director
Somak Raychadhury



Dean,
Core Academic Programmes
Dipankar Bhattacharya



Dean,
Visitor Academic Programmes
Kandaswamy Subramanian



Aseem Paranjape,
Head, Publications



Ranjeev Misra,
Head, Scientific Meetings



Dipankar Bhattacharya,
Head, Computing Facilities



Somak Raychaudhury,
Head, Infrastructural Facilities



A. N. Ramaprakash,
Head, Instrumentation



Surhud More,
Head,
Public Outreach Programmes



Gulab Dewangan,
Head, Teaching Programmes



Ranjeev Misra,
Head, ICARDs



Durgesh Tripathi,
Head, Library



R. Srianand,
Head, Observing Programmes
(At IGO & SALT)



Kandaswamy Subramanian,
Head, Grievance Cell

निदेशक की समीक्षा

वार्षिक प्रतिवेदन 2019 - 20



पिछले तीन दशकों से आयुका, खगोल विज्ञान और खगोल भौतिकी के लगभग सभी क्षेत्रों में मौलिक अनुसंधान एवं शिक्षण में सबसे आगे है। आयुका, LIGO- भारत और तीस मीटर टेलीस्कोप परियोजनाओं सहित राष्ट्रीय महत्व की बड़ी परियोजनाओं में अग्रणी भूमिका निभा रहा है, इसके अतिरिक्त आयुका, एक महत्वपूर्ण योगदानकर्ता के रूप में स्क्वायर किलोमीटर एरे और इसरो की विभिन्न अंतरिक्षीय परियोजनाओं समेत, एस्ट्रोसैट एवं भावी आदित्य - एल 1 परियोजनाओं में भी भागीदार है। आयुका में, एक लघु प्रमुख संकाय के सभी सदस्यों को प्रतिभाशाली विशेषज्ञों के रूप में उनके अनुसंधानिक क्षेत्रों में किये गए अनुसन्धान के लिए राष्ट्रीय एवं अंतर्राष्ट्रीय समुदायों द्वारा मान्यता प्रदान की गई है। उन्हें ऐसी सर्वोच्च मान्यता प्राप्त अनुसंधान बैठकों के अंतर्गत वार्ता देने हेतु आमंत्रित किया गया , जिसमें शामिल अधिकांश संगठन एवं समितियाँ विश्व भर में महत्वपूर्ण निर्णय लेने के लिए जानी जाती हैं।

इस संदर्भ में, मैं इसरो के एस्ट्रोसैट वेधशाला पर लगे अल्ट्रा वायलेट इमेजिंग टेलीस्कोप (UVIT) का उपयोग करके दूरस्थ-आकाशगंगा AUDFs01 से अति चरम यूवी प्रकाश की हाल ही में हुई खोज का भी उल्लेख करना चाहूंगा, जिसे एक अल्ट्रा-डीप सर्वेक्षण के अंग के रूप में,आयुका के ही एक वैज्ञानिक प्रो. श्याम.एन.टंडन के नेतृत्व में एक टीम द्वारा डिजाइन और निर्मित किया गया था। आयुका के प्रमुख संकाय के सदस्य प्रो. कनक साहा के नेतृत्व में एक वैश्विक टीम के सहयोग से इस खोज पर काम लगभग दो वर्ष पूर्व शुरू किया गया था। खगोलविद लंबे समय से प्रारंभिक ब्रह्मांड में पुनःआयनीकरण के स्रोतों को तलाश रहे थे और यह खोज, प्रक्रम को समझने में मदद करती हैं। हालाँकि ये आकाशगंगाएँ अत्यधिक यूवी विकिरणों का उत्सर्जन करती हैं, अतः इनका पता लगाना बहुत कठिन हैं। और यहाँ तक कि इस प्रकार की आकाशगंगाओं को पिछले यूवी टेलिस्कोप, जैसे नासा के हबल स्पेस टेलीस्कोप या गैलेक्स द्वारा भी स्पॉट नहीं किया गया है।

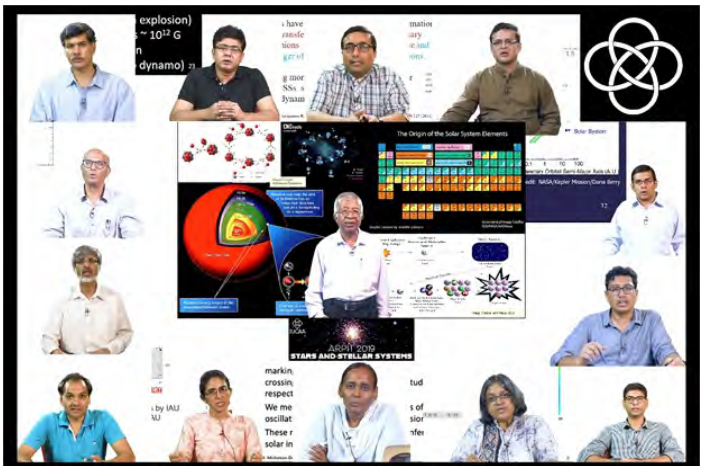
आयुका में, इस समय कुल मिलाकर 27 फैकल्टी एवं एमेरिटस प्रोफेसर, 31 पोस्ट-डॉक्टरल फेलो, तथा 61 पी.एच.डी स्कॉलर्स हैं। जिन्होने, सामूहिक रूप से ऐसे 134 समकक्ष समीक्षित शोध आलेखों का प्रकाशन किया, जिनका औसत इम्पैक्ट फैक्टर 5 से अधिक है। हमें इस पर बहुत गर्व है, क्योंकि यह दर्शाता है कि हमारे सहकर्मी अपने शोध में न केवल अत्यधिक सक्षम हैं, अपितु वे इस विषय पर संतोषजनक प्रभाव डालने में भी सफल रहें हैं। इस वर्ष के दौरान, आयुका के पांच शोधार्थियों ने पीएचडी की डिग्री प्राप्त की हैं। इससे भी अधिक सुखद यह हैं कि आयुका के 173 अभ्यागत सहभागी, जोकि वर्तमान में भारतीय विश्वविद्यालयों और कॉलेजों के संकाय सदस्य हैं और जिनके शोधों को आयुका द्वारा प्राप्त सहयोग के परिणामस्वरूप, उन्होंने इसी अवधि (अपने कार्यकाल)के दौरान 308 समकक्ष-समीक्षा पत्र प्रकाशित किए हैं। इस संख्या में पिछले कुछ वर्षों में काफी बढ़ोतरी हुई है, जो स्पष्ट रूप से इंगित करता है कि आयुका विश्व भर में उच्च शैक्षणिक संस्थानों में A & A अनुसंधान को प्रोत्साहित करने तथा उनको विकसित करने में बहुत प्रभावी रहा है। इसके साथ ही, राष्ट्रीय एवं अंतरराष्ट्रीय समुदायों के सदस्यों के बीच सक्रिय सहयोग को बढ़ावा देने हेतु उचित सुविधाएँ एवं वातावरण को भी प्रदान किया है।

इस वर्ष के दौरान, हमने अपने प्रमुख संकाय के चार नए सदस्यों का स्वागत किया, जिनके नाम हैं, देबारती चैटर्जी, सुभादीप डे, दीपांजन मुखर्जी, और निशांत के. सिंह, जिन्होंने हमें क्रमशः सेंटर नेशनेल डे रिसर्च साइंटिफिक, केन, फ्रांस, सी. एस. आई. आर - राष्ट्रीय भौतिक प्रयोगशाला, नई दिल्ली, यूनिवर्सिटिया डिली स्टडी डी टोरिनो, इटली एवं मैक्स प्लैंक इंस्टीट्यूट फॉर सोलर सिस्टम रिसर्च, गोटिंगेन, जर्मनी से क्रमशः जोड़ा है। जॉयदीप बागची हमारे प्रमुख संकाय के सदस्य, जिन्होने इस वर्ष के दौरान सेवा-निवृत्ति प्राप्त की, और जिन्हें आयुका में रेडियो भौतिकी प्रयोगशाला की देखरेख हेतु, पुनः एक अल्पकालिक अनुबंध के अंतर्गत बतौर सलाहकार के रूप में नियुक्त किया गया है। आयुका के ही एक अन्य प्रमुख संकाय

सदस्य तरुण सौरदीप, जिन्होने आई.आई.एस.ई.आर,पुणे, में प्रोफेसर एवं भौतिकी के अध्यक्ष के रूप में नियुक्ति प्राप्त की है।

आयुका के 31वें स्थापना दिवस का व्याख्यान 29 दिसंबर, को भारत सरकार के प्रधान वैज्ञानिक सलाहकार - के. विजयराघवन के द्वारा दिया गया, जोकि विकासात्मक जीवविज्ञान, अनुवांशिकी तथा न्यूरोजेनेटिक्स के क्षेत्र में एक प्रतिष्ठित प्रोफेसर हैं। उनके द्वारा दिए गए व्याख्यान का शीर्षक था "मंथन:- आंकड़ों के मंथन से प्राप्त आशा एवं आशंकाएँ", और जिसमें बताया गया कि, आज मानव समाज को एक ऐसे युग के समक्ष असंख्य प्रश्नों एवं चुनौतियों का सामना करना पड़ रहा है, जहाँ सभी प्रकार की सूचनाओं का प्रसंस्करण तेजी से जटिल मशीनों या कृत्रिम बुद्धिमत्ता को सौंपा जा रहा है। विजयराघवन ने यह माना कि, ज्ञान हमेशा वह कुंजी है जो सामर्थ्य का द्वार खोलती है, लेकिन आज लगभग न के बराबर लोग इस 'कुंजी' को साझा करने में विश्वास रखते हैं।

इसी अभ्यागमन के दौरान, विजयराघवन जी ने एस्ट्रोनॉमी सेंटर फॉर एजुकेटर्स-भवन का उद्घाटन भी किया। इस भवन और इसकी गतिविधियों के संचलन हेतु इसका वित्तीय पोषण मानव संसाधन विकास मंत्रालय द्वारा PMMMNMTT योजना के अंतर्गत किया जाता है। एस्ट्रोनॉमी सेंटर फॉर एजुकेटर्स एवं नेशनल रिसोर्स सेंटर फॉर A & A, जिसका संचालक आयुका है और जिसके तहत शिक्षण (ARPIT) में वार्षिक रिफ्रेशर कार्यक्रम के लिए "स्टार्स एंड स्टेलर सिस्टम्स" नामक एक ऑनलाइन पाठ्यक्रम को विकसित किया है। SWAYAM नामक मंच के जरिये इन ऑनलाइन व्याख्यानों को देश भर में फैले, 8 उच्च शिक्षा और अनुसंधान संस्थानों के 13 खगोल भौतिकविदों द्वारा रिकार्ड किया गया, मूलभूत आवश्यक शिक्षा-विज्ञान पर चल रहे व्याख्यान के दौरान ही, इस क्षेत्र में आगामी कार्यक्षेत्रों पर जोर देते हुए संबंधित क्षेत्रों में हाल के घटनाक्रमों के बारे में बताया गया।



आयुका के सदस्यों में से जहाँ एक ओर, प्रो.टी. पद्मनाभन को एम.पी. बिड़ला मेमोरियल अवार्ड से सम्मानित किया तो वहीं दूसरी ओर, प्रो.कंदस्वामी सुब्रमण्यन का भारतीय राष्ट्रीय विज्ञान अकादमी द्वारा फेलो के रूप चुनाव किया गया है। अव्यर्थना घोष (आई.आई.एस.ई.आर। कोलकाता की छात्रा, जोकि आयुका की देख-रेख में अपने शोध पर कार्य कर रहीं हैं) को एस्ट्रोनॉमिकल सोसाइटी ऑफ इंडिया द्वारा के.डी.अभ्यंकर बेस्ट थीसिस प्रस्तुति हेतु पुरस्कृत किया गया है। प्रख्यात प्रो.जयंत वी. नार्लीकर को जस्टिस महादेव गोविंद रानाडे मेमोरियल अवार्ड प्रदान किया गया है। इसके अतिरिक्त, केरल विश्वविद्यालय द्वारा डॉक्टर ऑफ साइंस (ऑनोरिस कॉसा), ब्रह्मभूषण पुरस्कार, ब्राह्मण सेवा मंडल-मुंबई द्वारा, बनारस हिंदू विश्वविद्यालय द्वारा एक विशिष्ट पूर्व छात्र का सम्मान, कलकत्ता विश्वविद्यालय द्वारा सर आशुतोष मूकर्जी मेमोरियल मेडल तथा सर डॉ. एम.एस. गोखले एजुकेशन सोसायटी, नासिक द्वारा गोसावी उत्कृष्टता पुरस्कार जैसे विभिन्न पुरस्कारों से सम्मानित किया गया है। प्रो.अजीत केम्भवी एवं प्रो.पुष्पा खरे (आयुका के पूर्व अभ्यागत सहयोगी) को उनकी मराठी पुस्तक "गुरुत्वीय तरंग - विश्व दर्शनाचे नवे साधना" (गुरुत्वीय तरंगें - ब्रह्माण्ड को देखने एवं समझने हेतु एक एक नवीन साधन) के लिए "महात्मा ज्योतिराव फुले पुरस्कार" से महाराष्ट्र राज्य साहित्य अणि संस्कृति मण्डल द्वारा सम्मानित किया गया है। हाल ही में, आयुका को भारत सरकार द्वारा बतौर पुणे सूचना संघ के पहले चरण का नेतृत्व करने के लिए चुना गया है, जोकि एक व्यापक स्तर पर वैश्विक परियोजनाओं को शुरू करने के लिए पुणे में शैक्षिक एवं अनुसंधान संस्थानों तथा उद्योग को एक साथ लाएगा; जिसके अंतर्गत समाज को सामान्य रूप से लाभान्वित करने के लिए, पर्यावरण, शिक्षा, स्वास्थ्य, एकीकृत यातायात एवं परिवहन, इलेक्ट्रिक मोबिलिटी, जल प्रबंधन, आदि शामिल हैं। भारत सरकार के प्रमुख वैज्ञानिक सलाहकार

कार्यालय, द्वारा बेंगलुरु और हैदराबाद में दो अन्य सूचना संघों की स्थापना की गई है।

आयुका ने, अपने जनसंपर्क गतिविधियों के माध्यम से, माध्यमिक विद्यालयों के छात्रों तथा जनमानस के बीच अपनी लोकप्रियता को बरक़रार रखा है। स्थानीय स्कूली छात्रों के लिए प्रत्येक माह के द्वितीय शनिवार को नियमित व्याख्यान / प्रदर्शन कार्यक्रम आयोजित किए जा रहें हैं, जोकि बहुत लोकप्रिय हैं। परिणामतः ऐसे हर एक मौके पर, आयुका के चंद्रशेखर सभागार में स्थानीय समुदाय के छात्रों तथा दूरदराज़ से आए छात्रों का मानो एक सैलाब सा आ जाता है। इसके अलावा, आयुका के जनसम्पर्क केंद्र द्वारा गर्मियों की छुट्टियों के दौरान स्कूल के छात्रों के ग्रीष्मकालीन कार्यक्रम एवं खगोल विज्ञान शिविर ने बड़ी संख्या में स्कूली छात्रों को आकर्षित किया। ये गतिविधियाँ , 10,000 से भी अधिक छात्रों तक अपनी पहुँच को बढ़ाने में सफल रहा हैं। राष्ट्रीय विज्ञान दिवस कार्यक्रम के अवसर पर आयुका ने इस वर्ष, आयुका परिसर एवं आयुका गिरेवली वेधशाला में, 27 और 28 फरवरी, 2020 के दौरान स्कूली छात्रों के लिए दो-दिवसीय प्रदर्शन, व्याख्यान, पोस्टर, मॉडल प्रस्तुतियां तथा स्कायवाच के साथ-साथ विभिन्न प्रतियोगिताओं को भी आयोजित किया। इस वर्ष अर्थात 2020 में इन गतिविधियों ने 12,500 से भी अधिक छात्रों एवं जन-साधारण को आकर्षित किया। इनके अलावा, प्रत्येक गुरुवार को आयुका परिसर में सार्वजनिक भ्रमण तथा आकाश की स्थिति को ध्यान में रखते हुए ,प्रत्येक शुक्रवार को स्काय-वाच कार्यक्रम भी होते। आयुका के जनसंपर्क गतिविधियों के तहत, महाराष्ट्र के विभिन्न हिस्सों में आयोजित किये जाने वाले व्या-ख्यान / प्रदर्शन / कार्यशालाएं शामिल थे - जिसमें हिंगोली जिले में LIGO-भारत कार्यस्थल तथा आयुका के अपने गिरावली वेधशाला के आस - पास के ग्रामीण जनसंपर्क कार्यक्रम भी शामिल थे।

आयुका के जो मुख्य उद्देश्य रहें हैं ; उसमें अपने बल पर सशक्त अनुसंधान कार्यक्रमों का संचालन करना, भारतीय विश्वविद्यालय क्षेत्र के भीतर उत्कृष्ट केंद्र प्रदान करना, भारतीय विश्वविद्यालयों में सक्रिय समूहों के न्यूक्लियेशन और विकास को बढ़ावा देने में सहयोग करना, तथा एक फील्ड स्टेशन एवं संसाधन केंद्र के रूप में कार्यशील रहना। इसके अलावा, भारत और पड़ोसी देशों में A & A गतिविधियों के लिए सामान्य मार्गदर्शन और सहायता प्रदान करते रहना शामिल है। इसे सफल बनाने के लिए, आयुका द्वारा आगंतुक शैक्षणिक कार्यक्रम तथा कई स्कूली कार्यशालाओं का आयोजन विभिन्न भारतीय विश्वविद्यालयों / कॉलेजों में किया जाता है। जिसके माध्यम से भारतीय विश्वविद्यालयों एवं कॉलेजों के छात्रों और संकाय सदस्यों को पर्याप्त अवसर प्रदान भी किये जातें हैं। इसने, अभ्यागत सहयोगियों के एक ऐसे नेटवर्क-निर्माण के सृजन को भी सुदृढ़ बनाया है, जोकि कई अन्य भारतीय विश्वविद्यालयों / कॉलेजों के संकाय सदस्य हैं, और साथ ही जो अब आयुका परिवार का एक अभिन्न अंग भी बन गए हैं। इसका पूरा श्रेय ,आयुका के साथ जुड़े हुए संपूर्ण प्रतिभाशाली कार्मिकों (प्रमुख एवं संविदात्मक) द्वारा कड़ी मेहनत और समर्पण को जाता है। मैं उनमें से हर एक के प्रति पूर्ण कृतज्ञता के साथ आभार व्यक्त करता हूँ।

हमारे गवर्निंग बोर्ड के अध्यक्ष डॉ. के.कस्तूरीरंगन, परिषद् के अध्यक्ष डॉ. धीरेन्द्र पी. सिंह एवं मार्गदर्शक मंडल की तरफ से मैं यू.जी.सी के अध्यक्ष के प्रति तहेदिल से कृतज्ञता व्यक्त करना चाहता हूँ। हम पूरी निष्ठा से, विश्वविद्यालय अनुदान आयोग एवं भारत सरकार के मानव संसाधन विकास मंत्रालय तथा उसके अधिकारियों तथा कार्मिकों से प्राप्त सहयोग, परामर्श एवं समर्थन को अभिस्वीकृत करते हैं।

सोमक रायचौधुरी
निदेशक, आयुका



IUCAA LONG SERVICE AWARDS

Standing (L to R): Mukund S. Sahasrabudhe, Pravinkumar A. Chordia, Senith S. Samuel, Rajesh D. Pardeshi, Bhimpuri S. Goswami, Nirupama U. Bawdekar, Manjiri A. Mahabal, Neelima S. Magdum, Vyankatesh A. Samak, Bhagiram R. Gorkha, Hillol K. Das, Kumar B. Munuswamy, Gajanan B. Gaikwad, Vilas B. Mestry, Santosh N. Khadilkar, Balaji V. Sawant, Deepak R. Shinde, and Shashikant G. Mirkute



Sitting (L to R) : Niranjan V. Abhyankar, Varun Sahni, T. Padmanabhan, Mangala J. Narlikar, Jayant V. Narlikar, and Somak Raychaudhury

Members who could not receive the Awards in person that day: Sandeep L. Gaikwad, Varsha R. Surve, and Deepika M. Susainathan

DIRECTOR'S REPORT



For the last three decades, IUCAA has been at the forefront of fundamental research and teaching in almost all areas of Astronomy and Astrophysics (A & A). IUCAA continues to play a leading role in large projects of national importance, including LIGO-India and the Thirty Metre Telescope projects, and is a significant contributing partner in the Square Kilometre Array and various space projects of ISRO, including AstroSat and the future Aditya–L1. All members of the small Core Faculty at IUCAA have been recognised in the national and international communities as talented experts in their areas of research. They have been invited to give talks in well-recognised research meetings, and most of them are in important decision-making committees and organisations all across the world.

In this context, I would mention the recent discovery of extreme UV light from the distant galaxy AUDFs01, using the Ultra Violet Imaging Telescope (UVIT), on board ISRO's AstroSat, which was designed and built by a team led by IUCAA scientist, Shyam N. Tandon, as part of an ultra-deep survey. The work on this discovery was started about two years back, by a global team led by IUCAA Core Faculty member Kanak Saha. Astronomers have long been looking for sources of reionization in the early universe, and this discovery helps to understand the process. Although these galaxies emit extreme UV radiation, spotting them is very difficult, and galaxies such as this have not been spotted by previous UV telescopes such as NASA's Hubble Space Telescope or GALEX.

IUCAA currently has 27 Core Faculty and Emeritus Professors, 31 Post-Doctoral Fellows, and 61 PhD Scholars. They have collectively published 134 peer-reviewed papers, with a mean impact factor of over 5. We are very proud of this, since it shows that our colleagues are not just very productive in their research, but they are making a substantial impact on the subject. During this year, five IUCAA students have obtained PhD degrees. Even more gratifying is the fact that the 173 Visiting Associates of IUCAA, who are faculty members at Indian Universities and Colleges, supported in their research by IUCAA, have published 308 peer-reviewed papers during the same period. This number has increased over the years, and clearly indicates the impact IUCAA has had in promoting and nurturing A & A research at institutions of higher education all over the country, and has provided facilities and the right atmosphere for nurturing active collaboration between members of the community of associates and the national and international communities.

During this year, we welcomed four new members to our Core Faculty, namely, Debarati Chatterjee, Subhadeep De, Dipanjan Mukherjee, and Nishant K. Singh, who have joined us from the Centre Nationale de Researche Scientifique, Caen, France; CSIR – National Physical Laboratory, New Delhi; Universita degli Studi di Torino, Italy; and Max Planck Institute for Solar System Research, Gottingen, Germany, respectively. Joydeep Bagchi, our Core Faculty has superannuated during this year, and he has been appointed on a short contract as a Consultant to look after the Radio Physics Laboratory at IUCAA. Tarun Souradeep, another member of the Core Faculty, has joined IISER, Pune as Professor and Chair of Physics on deputation.

The 31st IUCAA Foundation Day Lecture was delivered on December 29, 2019 by K. VijayRaghavan, Principal Scientific Adviser to the Government of India, who is a distinguished professor in the field of developmental biology, genetics and neurogenetics. His lecture was titled, 'Manthan: The promises and perils of the churning of data', and dealt with the myriad questions and challenges facing human society in an age where the processing of information of all kinds is being handed over to increasingly complex machines or artificial intelligence. K. VijayRaghavan posited that 'knowledge has always been the key that opens the door to power, but today fewer and fewer people share that key'.



During the same visit, K. VijayRaghavan also inaugurated the building of the Astronomy Centre for Educators. The building and its activities are funded by the Ministry of Human Resources Development under the PMMMNMTT Scheme. The Astronomy Centre for Educators, and the National Resource Centre for A &A, hosted by IUCAA have developed an online course titled, `Stars and Stellar Systems' for Annual Refresher Programme in Teaching (ARPIT). These online lectures for the SWAYAM platform were recorded by 13 Astrophysicists from 8 institutions of higher education and research spread across the country, highlighting recent developments in the respective areas, while touching upon the basic required pedagogy, and emphasising emerging areas in the field.

Among the members of IUCAA, T. Padmanabhan has been given the M. P. Birla Memorial Award, and Kandaswamy Subramanian has been elected a Fellow of the Indian National Science Academy. Avyarthana Ghosh (IISER Kolkata student working on her thesis at IUCAA) has been given the K. D. Abhyankar Best Thesis Presentation Award, by the Astronomical Society of India.

Emeritus Professor Jayant V. Narlikar has been presented the Justice Mahadeo Govind Ranade Memorial Award, Doctor of Science (Honoris Causa) by the University of Kerala, the Brahmabhushan Puraskar by the Brahmin Seva Mandal, Mumbai, a Distinguished Alumnus Award by the Banaras Hindu University, Sir Asutosh Mookerjee Memorial Medal by the University of Calcutta, and the Sir Dr. M.S. Gosavi Excellence Award by the Gokhale Education Society, Nashik. Ajit Kembhavi and Pushpa Khare (Former Visiting Associate of IUCAA) have been awarded the "Mahatma Jyotirao Phule Puraskar" for their Marathi book "Guruttviy Tarang - Vishwdardshnache Nave Sadhan" (Gravitational Waves - A New Tool to Watch and Understand the Universe) by the Maharashtra Rajya Sahitya ani Sanskruti Mandal.

Recently, IUCAA has been selected by the Government of India to lead the first stage of Pune Knowledge Cluster, which will bring together educational and research institutions and industry in Pune to undertake global projects in Big Data, Environment, Education, Health, Integrated Traffic and Transportation, Electric Mobility, Water Management, etc. to benefit the society in general. Two other Knowledge Clusters have been established at Bengaluru and Hyderabad, by the office of the Principal Scientific Adviser to the Government of India.

IUCAA has continued to be at the forefront of science popularisation and outreach activities for high school students and the general public. Regular Second Saturday Lecture/Demonstration Programmes for local school students have been conducted, and are very popular, and on every one of these occasions, the Chandrasekhar Auditorium has overflown with students from the local community and from afar. Moreover, the School Students' Summer Programme and the Astronomy Camp during the summer attracted a large number of school students. These activities have reached over 10,000 students. The National Science Day programmes, consisting of various competitions for school students, demonstrations, lectures, posters and model presentations, night sky watching, etc., were conducted in IUCAA campus, and IUCAA Girawali Observatory region, for two days during February 27 and 28, 2020, and attracted more than 12,500 students and general public. Apart from these, there were public visits to IUCAA campus on every Thursday, and sky watching programmes on every Friday, if the sky conditions were suitable. Outreach activities included lectures/demonstrations/workshops conducted at different parts of Maharashtra and elsewhere- this included our rural outreach programmes around the LIGO-India site in the Hingoli district, and in the vicinity of IUCAA's own Girawali observatory.

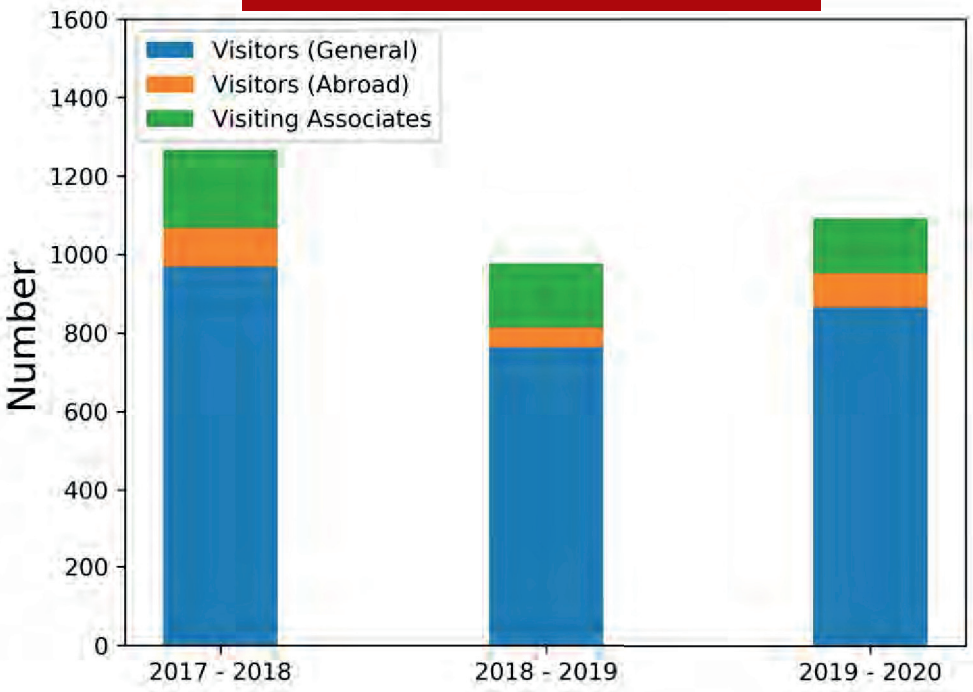
The main objectives of IUCAA have been to conduct vigorous research programmes of its own, and to provide a centre of excellence within the Indian University sector, and to help to promote the nucleation and growth of active groups in Indian Universities, and functions as a field station and resource centre, and provide general guidance and help for A & A activities in India and neighbouring countries. To achieve these, the Visitor Academic Programmes, and numerous workshops and schools conducted at IUCAA, and at various Indian Universities/ Colleges give enough openings to students and faculty members of Indian Universities and Colleges. This enabled the creation of a network of Visiting Associates, who are faculty members of various Indian Universities/ Colleges, and they became a part of IUCAA family. All of this owed to a great deal of hard work and dedication by the entire talented staff (core and contractual) of IUCAA. I wish to express my sincere thanks to every one of them.

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

Somak Raychaudhury
Director,
IUCAA, Pune.

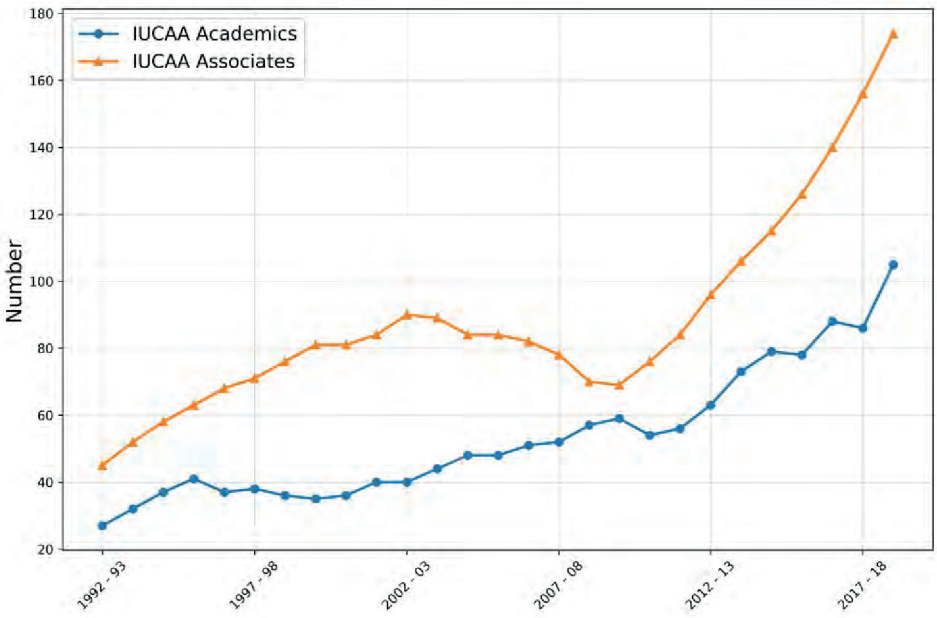
IUCAA IN NUMBERS

Visitors to IUCAA

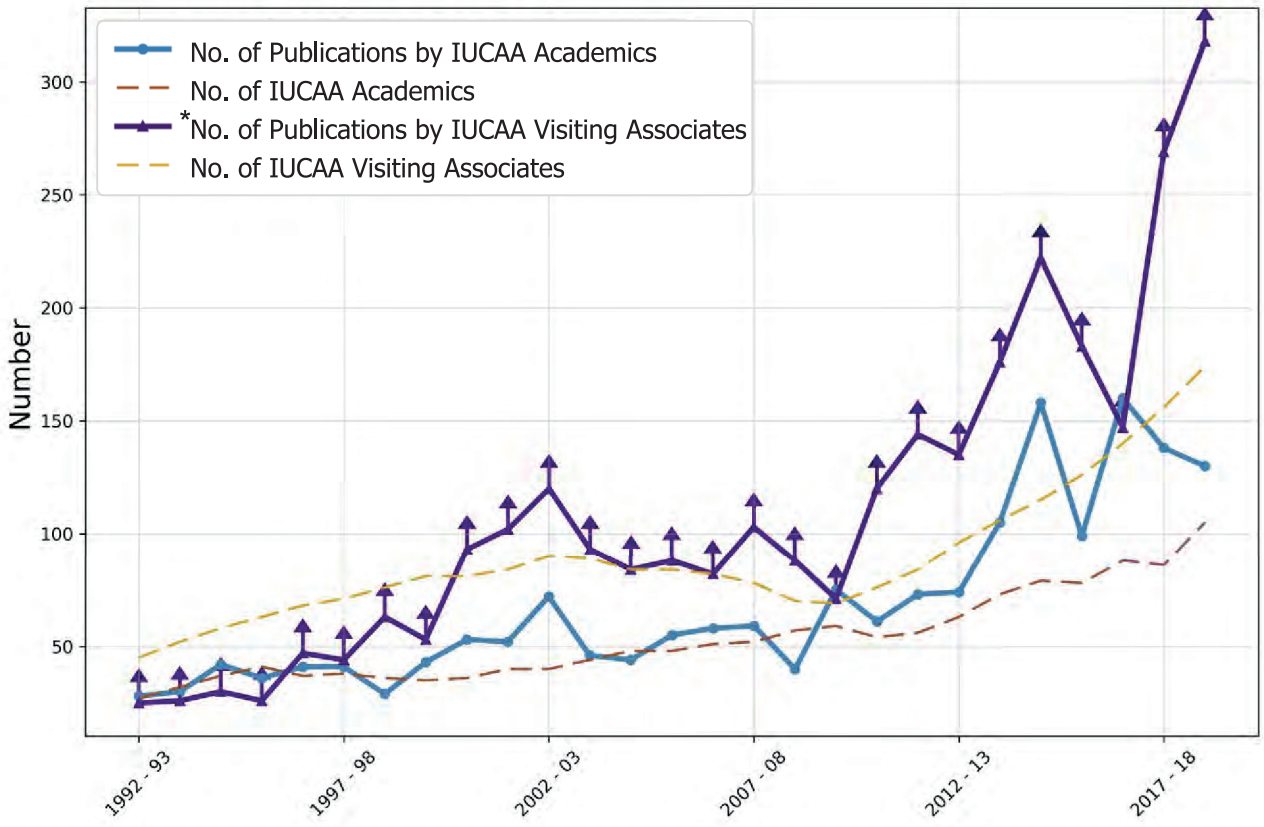


Since its inception, the IUCAA extended family of Visiting Associates has seen a steady growth over time,with an academic strength today nearly thrice its original number.

IUCAA Family across the Years



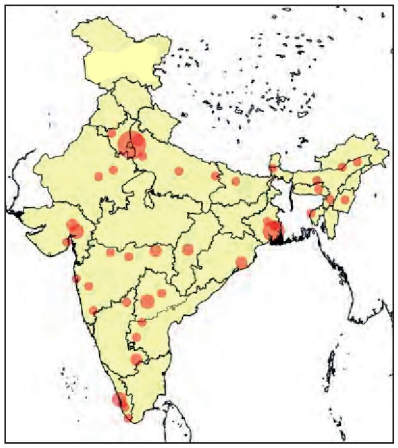
Publications across the Years



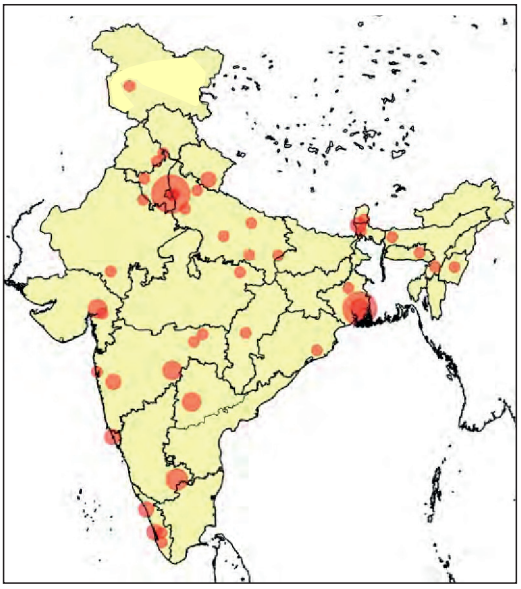
Number of Publications by IUCAA Visiting Associates are underestimated.

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

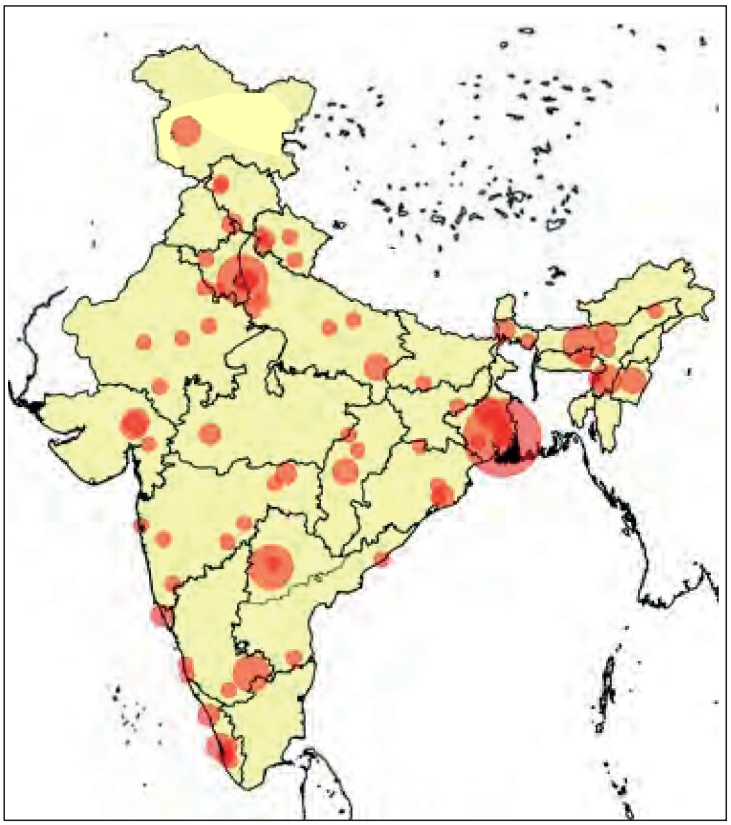
IUCAA Visiting Associates across India



1997-1998



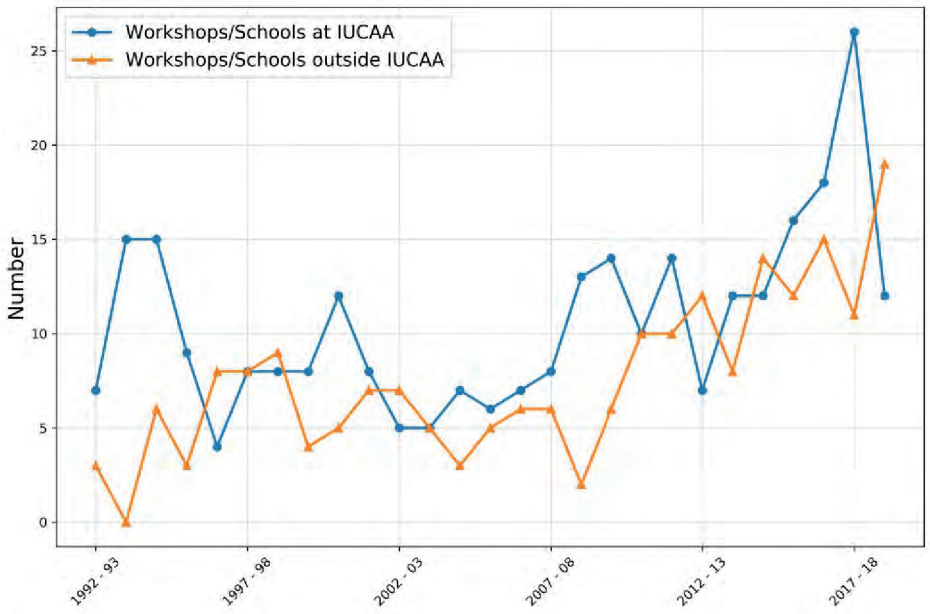
2007-2008



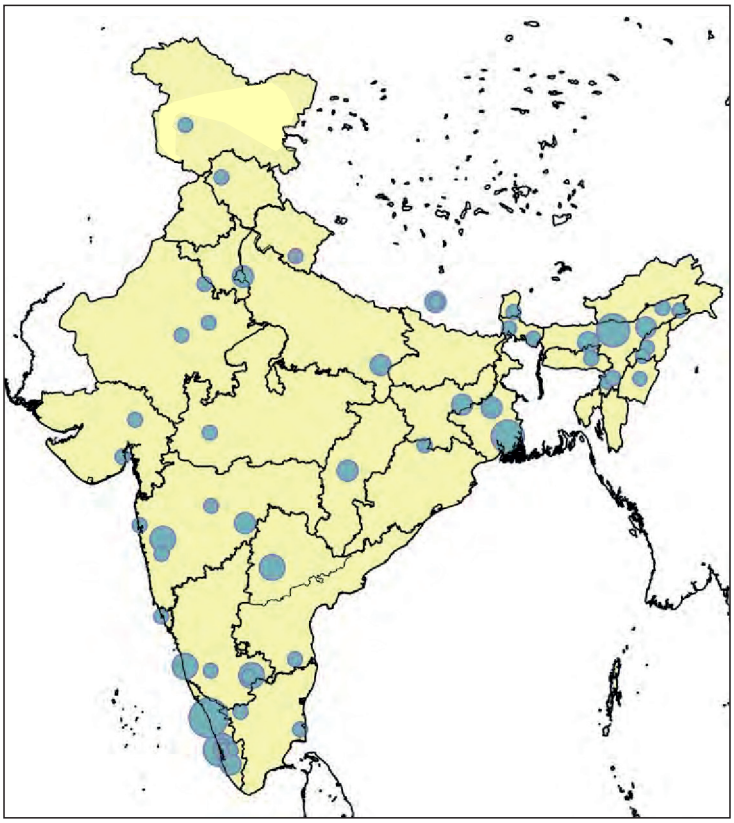
2017-2019

Diverse set of IUCAA Visiting Associates has continued to expand both in numbers as well as geographically, with significant representation today from the remotest parts of the country.

Workshops / Schools at IUCAA and outside IUCAA



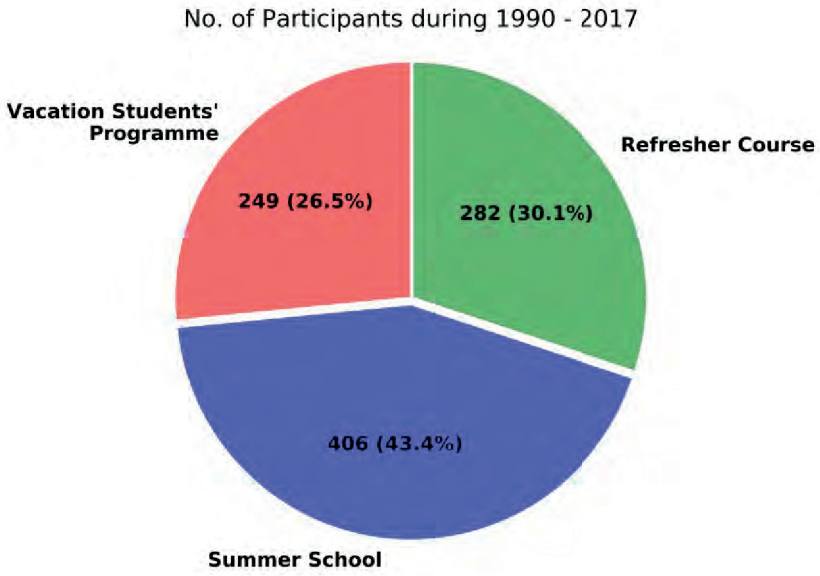
IUCAA is committed to fostering Astronomy and Astrophysics in the Universities, primarily through an increasing frequency of Workshops and Schools, both at and outside IUCAA.



Number of participants in workshops/schools at IUCAA is approximately 500 per year during 2015-2019

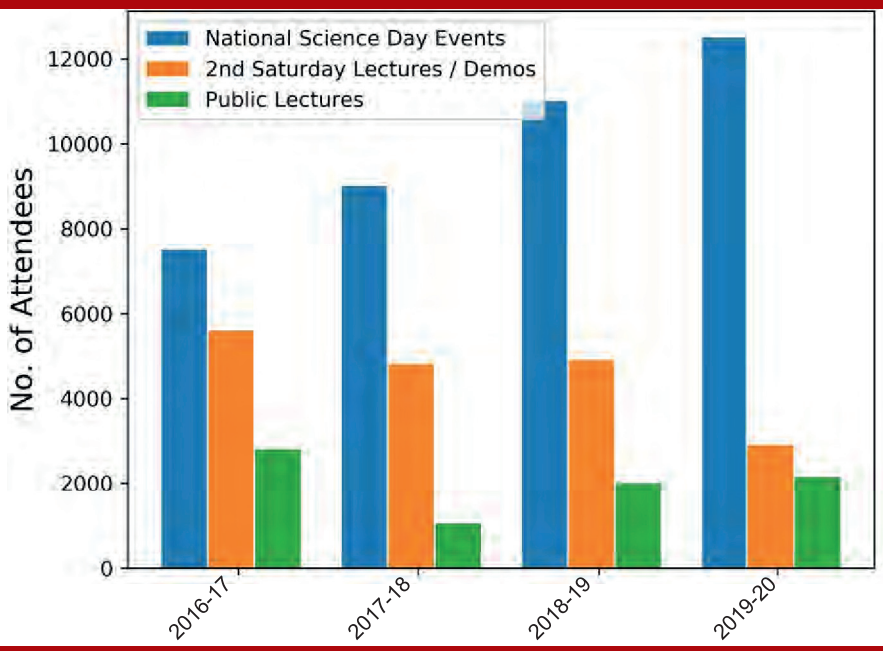
Summer Programmes at IUCAA

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



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

Public Outreach Events at IUCAA



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

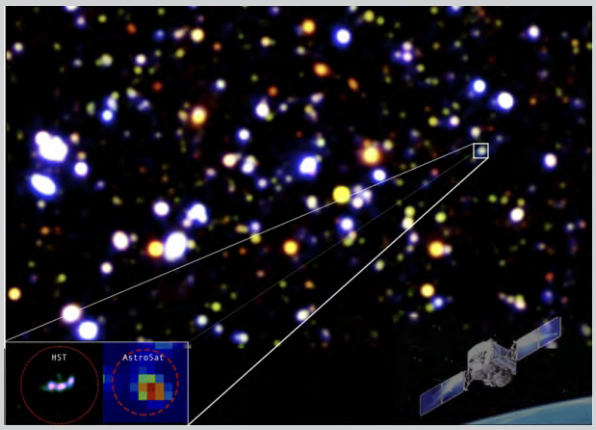
अंतरिक्ष में एस्ट्रोसैट की गतिविधियाँ

अंतरिक्ष में एस्ट्रोसैट के पांच वर्ष हुए पूरे

हाल ही में, 28 सितंबर 2020 को भारतीय बहुतरंगीय स्पेस एस्ट्रोनॉमी मिशन एस्ट्रोसैट ने अंतरिक्षीय - कक्षा में पांच साल पूरे कर लिए हैं। आयुका, इस मिशन के संकल्पन से लेकर प्रापण और उसके बाद के उपयोग तक, बेहद गंभीरता से शामिल रहा है। इस अल्ट्रावॉयलेट दूरबीन परियोजना का नेतृत्व आयुका के एक वरिष्ठ प्रो. एस. एन. टंडन द्वारा किया गया। इसके लॉन्च होने के बाद, इसरो से प्राप्त वित्तीय सहायता के माध्यम से आयुका ने एस्ट्रोसैट साइंस सपोर्ट सेल को चलाने की जिम्मेवारी ली है, जो कि सम्पूर्ण भारतवर्ष एवम विदेशों में एस्ट्रोसैट के उपयोगकर्ताओं को सहायता और प्रशिक्षण प्रदान करता है। आयुका, इसके एक ऑन-बोर्ड उपकरणों में से, कैडमियम जिंक टेल्यूराइड इमेजर के लिए पेलोड ऑपरेशन सेंटर भी चलाता है।

इन पांच वर्षों के दौरान, आयुका के सदस्यों ने एस्ट्रोसैट के साथ व्यापक स्तर पर विभिन्न प्रकार के विज्ञान लक्ष्यों का अनुसरण किया है। इस गतिविधि के तहत, वे सावित्रीबाई फुले पुणे विश्वविद्यालय सहित कई कॉलेजों और विश्वविद्यालयों, जामिया मिलिया इस्लामिया, आई.आई.टी कानपुर, आई.आई.टी बॉम्बे, क्राइस्ट (भावी मान्यता प्राप्त) विश्वविद्यालय, तेजपुर विश्वविद्यालय, पैसिफिक विश्वविद्यालय, आई.आई.एस.ई.आर. मोहाली, आई.आई.एस.ई.आर. पुणे, महात्मा गांधी विश्वविद्यालय और आर.जे. कॉलेज मुंबई तथा कई अन्य विश्वविद्यालयों के अनुसंधान विद्वानों और संकायों के साथ सक्रिय रूप से सहयोग कर रहे हैं। । इस शोध के कुछ मुख्य अंश नीचे प्रस्तुत किए गए हैं।

तारे और आकाशगंगाएँ



एस्ट्रोसैट द्वारा हबल अत्यंत डीप फील्ड की ली गईं चौरंगी छवि। लाल और हरे रंग की छवि HST F814W और F606W बैंड से ली गईं हैं जबकि नीले और सियान रंगो वाली छवि UVIT F154W और N242W फिल्टर से अभिग्रहित की गईं हैं। छवि को आरेखित करने के लिए लिए HST और UVIT के बीच PSF मिलान एवं पुन: बानगी का उपयोग किया जाता है। AUDFs01 z = 1.42 पर स्थित है और जिसे 3.2 के संकेत-से -शोर अनुपात के साथ चरम-यूवी प्रकाश में पाया गया है। (साभार: कनक साहा)

एस्ट्रोसैट की प्रमुख गुणों में से एक है इसकी अल्ट्रा वायलेट इमेजिंग टेलीस्कोप (यूवीआईटी) की उत्कृष्ट इमेजिंग क्षमता, जिसने एस्ट्रोसैट को एक विस्तृत आकारीय क्षेत्र के लिए लगभग आधा डिग्री, यूवी बैंड में ब्रह्मांडीय पदार्थों की गहनतम (deeper) एवं स्पष्ट दोनों प्रकार की छवियों को हासिल करने में पहले से अधिक सक्षम बनाया है।

लाइमैन-सांतत्यक बैंड में पराबैंगनी प्रकाश, अंतरिक्षीय (intergalactic medium) माध्यम के आयनीकरण का मुख्य स्रोत है। कनक साहा, श्याम टंडन और सहयोगियों (2020) ने एस्ट्रोसैट UVIT का उपयोग सुदूर की विदित आकाशगंगाएँ (रेडशिफ्ट z = 1.42 पर) जो अपने आस - पास की लाइमैन-सांतत्यक विकिरण की प्रचुर मात्रा को स्रावित कर रही है, उनका पता लगाने के लिए किया। इस आकाशगंगा को AUDFs01 (एस्ट्रोसैट अल्ट्रा डीप फील्ड सोर्स 01) नाम दिया गया है, और यह उस महत्वपूर्ण भूमिका को प्रदर्शित करता है जो आकाशगंगाओं ने फैलने वाली अंतरआकाशगंगीय-गैस को अत्यधिक आयनीकृत रखने में निभाई है।

आस-पास की आकाशगंगाओं की विस्तृत यूवी इमेजिंग ने हाल ही में निर्मित तारों की उत्पत्ति के क्षेत्रों का खुलासा किया है और उनमें से कुछ आश्चर्यजनक एवं सीमांत स्थानों पर हैं - जैसे कि विजन, अपर्याप्त गैसीय आकाशगंगाएँ (उदाहरण के लिए, NGC 4571: कनक साहा और श्याम टंडन), और गैसीय धाराएँ "जेलिफ़िश" आकाशगंगाओं से छीन ली गईं (श्याम टंडन और सहयोगियों - जॉर्ज एट अल 2018) हमारी आकाशगंगा में गोलाकार तारा समूहों में से, जो कुछ सबसे पुराने पदार्थ हैं, उनके विकास के बारे में UVIT अध्ययन के द्वारा रोचक तथ्यों की जानकारी प्राप्त हुई है। उदाहरण के लिए, यूवी रंग-परिमाण आरेख के अध्ययन के माध्यम से यह पाया गया है कि तारक समूह NGC 1851 का गठन 3 अरब वर्ष से भिन्न आयु के कई सितारा समूहों के विलय से हुआ था (श्याम टंडन और सहयोगी - सुब्रमण्यम et al 2017)।

सक्रीय आकाशगंगाएँ

एस्ट्रोसैट एवं UVIT, अन्य एक्स-रे उपकरणों के साथ - सॉफ्ट एक्स-रे टेलीस्कोप (SXT), विशाल एक्स-रे आनुपातिक काउंटर क्षेत्र (LAXPC) और कैडमियम जिंक टेल्यूराइड इमेजर (CZTI) मिलकर एक बहुत व्यापक ऊर्जा पट्टिका पर, ब्रह्मांडीय स्त्रोतों का एक साथ अवलोकन करने की एक विशिष्ट क्षमता प्रदान करता है। यह क्षमता उन पदार्थों के अध्ययन के लिए विशेष रूप से महत्वपूर्ण है जिनकी विकिरण की तीव्रता समय के साथ बहुत तेजी से बदलती है। पदार्थों का ऐसा एक वर्ग सक्रिय आकाशगंगा होता है, जहां एक केंद्रीय सुपरमासिव (सूरज से द्रव्यमान का एक मिलियन से लाख गुना) ब्लैक होल अपने आसपास की गैसों तथा सितारों से घिरा हुआ है तथा जो इन सभी तरंग बैंडों पर बहुत अधिक जगमगातें हैं, साथ ही एक प्रबल जेट जैसे पदार्थ का उत्क्षेपण (इजेक्शन) भी करते हैं जो आगे चलकर प्रेक्षित उत्सर्जन में योगदान देता है। आयुका के वैज्ञानिक एस्ट्रोसैट (गुलाब देवांगन, रंजीव मिश्रा, सावित्री एझिकोड, प्रकाश त्रिपाठी, ज़हीर शाह) के माध्यम से कई अन्य सक्रिय आकाशगंगाओं का अवलोकन कर रहे हैं। ऐसा ही एक उदाहरण Seyfert-1 galaxy IC4329A है। जिन वर्णक्रमों को पराबैंगनी बैंड में देखा गया, उसने एक पतली, थोड़ी दूरी पर घूमने वाली इकाई जिसके माध्यम से ब्लैक होल तक सामग्री पहुंचती है, ऐसी एक अभिवृद्धि डिस्क" के लिए साक्ष्य प्रदान किया है। फिर भी; उम्मीदों से परे, यह डिस्क ब्लैक होल से अपेक्षाकृत बहुत दूरी (80-150 Gravitational radii) पर खंडित होती पाई जाती है। प्रवाह का आंतरिक भाग इस डिस्क संरचना का पालन नहीं करता है। प्रवाह का आंतरिक भाग अब इस डिस्क संरचना का हिस्सा बिलकुल नहीं है। UVIT, SXT और LAXPC से एक साथ डेटा की सचेत तुलना ने भी महत्वपूर्ण पहलुओं को प्रकट किया है कि अवलोकित उत्सर्जन कैसे उत्पन्न होता है। एक्स-रे बैंड में वर्णक्रमीय ढलान और अत्यधिक मंद एक्स-रे प्रवाह, दोनों ही यूवी विकिरण के चरणों में भिन्नता पाई जाती हैं। यह एक्स-रे उत्सर्जन का एक संकेतक है, जिसकी उत्पत्ति अभिवृद्धि डिस्क में उत्पन्न पराबैंगनी फोटॉनों के कॉम्पटन अप-स्कैटरिंग के परिणामस्वरूप होती है। जेट-प्रभुत्व वाले सक्रिय गैलेक्सी के एस्ट्रोसैट अवलोकन से पता चला है कि ब्रॉड बैंड एक्स-रे वर्णक्रम का महत्वपूर्ण रूप से घातांक -नियम के अनुरूप विचलन होता है, जोकि UVIT डेटा के साथ मिलकर, उत्सर्जन कण पैदा करने वाले अंतर्निहित कण वितरण की प्रकृति पर महत्वपूर्ण प्रभाव डालता है।

ब्लैक होल एक्स-रे बाइनरी (द्विआधारी) पद्धति

एस्ट्रोसैट एक्स-रे उपकरणों द्वारा अपनाई जा रही मुख्य विषय -वस्तु में से एक है न्यूट्रॉन सितारें और ब्लैक होल्स सहित सघन पदार्थों द्वारा उत्पादित तीव्र परिवर्तन के समृद्ध पैटर्न। तारकीय द्रव्यमान वाले ब्लैक होल्स एक बाइनरी सहचर के सहयोग से बड़े पैमाने पर एक विशेष प्रकार के द्रव्यमान का सहवर्धन करतें हैं, क्योंकि इन वस्तुओं के रूप में विकीर्ण पदार्थ गुरुत्वीय क्षमता वाले कुओं में सबसे गहराई तक प्रवेश करता है और सामान्य सापेक्षता के प्रभावों का डटकर सामना करता है। परिणामी तीव्रता का भिन्न-रूपों और वर्णक्रमीय आकृतियों को इसके द्रव्यमान और चक्रण सहित ब्लैक होल के गुणों का पता लगाने के लिए इस्तेमाल किया जा सकता है, और वे अभिवृद्धि प्रवाह में हाइड्रोडायनामिक प्रक्रियाओं को भी प्रकट कर सकते हैं।

उच्च ऊर्जा एक्स-रे के स्तर पर संवेदनशील-समय विश्लेषण करने की एस्ट्रोसैट की क्षमता प्रवाह के अंतर क्षेत्रों का पता लगाने के लिए एक आदर्श उपकरण है। ऐसे कई स्टेलर मास ब्लैक होल बाइनरी सिस्टम का एस्ट्रोसैट के माध्यम से आयुका के वैज्ञानिकों द्वारा अध्ययन किया गया है। इस सूची में Cyg X-1, Cyg X-3, GRS 1915 + 105, MAXI J1820 + 070, स्विफ्ट J1535-671, 4U1630-47, स्विफ्ट J1658.2-4242 जैसे कुछ नाम शामिल हैं। इनमें से कई मामलों में, निम्न ऊर्जा और उच्च ऊर्जा वाले एक्स-रे नें परिवर्तनशीलता की तुलना में अभिवृद्धि प्रवाह के आंतरिक क्षेत्रों एवं प्रवाह परिवर्तनशीलता के कारणों के बारे में हमारे ज्ञान को समृद्ध किया है। उदाहरण के लिए, यह अनुमान लगाया जा सकता है कि परिवर्तनशीलता के ब्रॉडबैंड शोर घटक अभिवृद्धि डिस्क के बाहरी भागों में उत्पन्न होने के कारण उत्पन्न होती है, जो अंदर की ओर पलायन करती है। इनमें से देखी गई, कुछ परिवर्तनशीलता में से कुछ अर्ध-आवधिक तथा दोलनी प्रकृति (QPO) की हैं। अक्सर, QPO की आवृत्ति को एक्स-रे प्रवाह के साथ सहसंबंधित पाया जाता है। खासतौर से, स्विफ्ट J1535-571 में QPO आवृत्ति और उच्च-ऊर्जा एक्स-रे वर्णक्रम ढलान के मध्य एक घनिष्ठ सहसंबंध को दर्शाया गया, जिसके अंतर्गत कॉमपिटाइजिंग क्लाउड को सम्मिलित करने हेतु सुझाव दिया गया। ब्लैक होल सिस्टम स्विफ्ट J1658.2-4242 में देखे गए QPO के ऊर्जा-निर्भर अस्थायी व्यवहार का एक विस्तृत-अध्ययन और अभिवृद्धि डिस्क के तापमान में भिन्नता एक तप्त कोरोना पर निर्भर करता है, जिसे उन दोनों के मध्य अंतराल के साथ समझाया जा सकता है। GRS 1915 + 105, एक 70-हर्ट्ज़ QPO सिस्टम, जिसके बारे में अब तक यह अवधारणा थी कि वह एक निश्चित आवृत्ति पर ही घटित होता है, एस्ट्रोसैट द्वारा की गई खोज में पाया गया, उसका सहसंबद्ध वर्णक्रमीय स्थिति के साथ दरअसल एक चर आवृत्ति में है। इस प्रणाली में एक और QPO जो कि 2 हर्ट्ज़ से 6 हर्ट्ज़ के बीच होता है, उसको ब्रॉडबैंड एस्ट्रोसैट स्पेक्ट्रा के विश्लेषण के माध्यम से ठीक वैसा ही अलग पाया गया जैसा कि डायनेमिक फ्रीक्वेंसी को डिस्क के माध्यम से ध्वनि क्रॉसिंग समय के व्युत्क्रम के रूप में परिभाषित किया गया था। इस माप में यह भी बताया गया कि यह ब्लैक होल अपने अधिकतम संभाव्य परिक्रमण अर्थात लगभग 90% की गति से घूम कर रहा है। एस्ट्रोसैट, मैक्सआई और चंद्र वेधशाला के साथ एक समन्वित वर्णक्रमीय अध्ययन के समय एक तीव्र गति से घूम रहे ब्लैक होल को भी "सिस्टम 4U1630-47" के तहत देखा गया। इन अवलोकनों के अंतर्गत सिस्टम द्वारा एक तीव्र गति (लगभग 350 किमी / सेकंड) की आयनित वायु का भी पता लगाया।

(रंजीव मिश्रा, दीपांकर भट्टाचार्य, यश भार्गव, वी. जितेश, बारी मकबूल, ज़हीर शाह, मयूख पहाड़ी एवं सहयोगी)

न्यूट्रॉन सितारों का अभिवर्धन

एस्ट्रोसैट द्वारा अध्ययन की जा रही सघन पदार्थों की एक और महत्वपूर्ण श्रेणी में न्यूट्रॉन सितारें शामिल हैं, जो स्वयं को उनके बेहद मजबूत चुंबकीय क्षेत्र से अलग करता है, इसके अलावा इसमें गिगा एवं तेरा-गॉस भी सम्मिलित हैं। न्यूट्रॉन तारों पर अभिवृद्धि इस प्रकार मजबूत हाईड्रोमैग्नेटिक (द्रवचुम्बकीय) प्रभावों के अधीन होती है, जोकि तीव्रता से परिवर्तन और वर्णक्रम पर अपने स्वयं के सांकेतिक छाप छोडतें हैं। कुछ सिस्टम, जिसमें न्यूट्रॉन तारे का प्रचक्रण भी प्रेक्षित प्रवाह के आवधिक मॉडुलन में खुद को प्रकट कर सकता है; ऐसे पदार्थों को "अभिवर्धन एक्स-रे पल्सर" कहा जाता है। एस्ट्रोसैट के माध्यम से जिस न्यूट्रॉन तारे के निम्न -द्रव्यमान एक्स-रे बाइनरी 4U1728-34 के समृद्ध अस्थायी प्रकृति का अध्ययन किया गया था, जिसमें एक ~ 820-हर्ट्ज़ QPO को दर्शाया गया, उसके अंतर्गत थर्मोन्यूक्लियर एक्स-रे विस्फोट और 363 हर्ट्ज़ पर एक ऐसे ही किसी आवधिक तीव्रता वाले भिन्न, एक्स-रे विस्फोट के दौरान न्यूट्रॉन तारे की प्रचक्रण आवृत्ति की पहचान की गई है। एस्ट्रोसैट ने विस्तृत ढंग से उच्च द्रव्यमान वाले एक्स-रे बाइनरी न्यूट्रॉन सितारा सिस्टम के चमकीले एक्स-रे विस्फोट का भी अवलोकन किया 4U0115 + 63 तथा साथ ही 1 और 2 मिलीहर्ट्ज़ पर ऐसे QPOs की खोज की जो न्यूट्रॉन तारे के मजबूत चुंबकीय क्षेत्र के साथ प्रवाहित होने वाले पदार्थ की अंतः क्रिया में उत्पन्न होते हैं। चुंबकीय क्षेत्र "साइक्लोट्रॉन रेजोनेंस स्कैटरिंग फीचर्स" के रूप में एक्स-रे वर्णक्रम में भी प्रकट होता है- जैसे कि गर्तीय अवशोषण-जिनके ऊर्जा मूल्य स्पष्टतः क्षेत्रीय बल से संबंधित हैं।

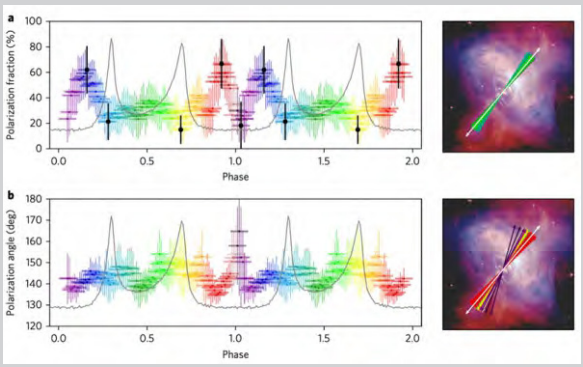
इस तरह का एक सिस्टम , Her X-1, को साइक्लोट्रॉन सुविधा की ऊर्जा का एक दीर्घकालिक रूप दिखाने के लिए जाना जाता है, जो उत्सर्जन क्षेत्र में क्षेत्रीय बल के क्रमिक परिवर्तन के बारे में बतलाता है। आयुका के अनुसंधानकर्ताओं ने कई विभिन्न आँकड़ों तथा संयुक्त एस्ट्रोसैट खोजों के साथ इस सिस्टम का पालन किया है, और इन खोजों के अंतर्गत ये पाया कि, पिछले दो दशकों में इस सिस्टम के प्रत्यक्ष क्षेत्रीय बल में क्रमशः प्रथम 15 वर्षों के दौरान कमी आई है और, तब से इसे एक स्थिरांक मान लिया गया है। इसमें बताया गया है कि ,यह समय के साथ चुंबकीय ध्रुव की ओर धीरे-धीरे बढ़ता हुआ एक ऐसी अधिकतम स्थिर ऊंचाई पर पहुंचता है, जिस पर पदार्थ का अन्तर्वाह और बहिर्वाह एक दूसरे को संतुलित करते हैं। (जयश्री रॉय, सुमन बाला, दीपांकर भट्टाचार्य, रंजीव मिश्रा एवं सहयोगी)

गामा-रे विस्फोट

एस्ट्रोसैट पर कैडमियम जिंक टेलराइड इमेजर पेलोड गामा रे विस्फोट (जीआरबी) का एक सफल संसूचक रहा है। इसके चालू करने के कुछ घंटो के अंदर ही इसके प्रथम विस्फोट का पता चल गया, और ऑपरेशन के पांच साल में कुल गिनती 250 से अधिक तक पहुंच गई। इन सभी GRBs के सम्पूर्ण आँकड़ों का प्रक्रमण और विश्लेषण आयुका स्थित पेलोड ऑपरेशन सेंटर में होता है, और किसी भी खोज से सम्बंधित जानकारी तत्काल ही सार्वजनिक डोमेन में पोस्ट की जाती है। GRBs के तीव्र उत्सर्जन के बहु-बैंड अध्ययन को सुविधाजनक बनाने के अतिरिक्त, CZTI ने एक गुरुत्वीय तरंग घटना (GW170104) के प्रस्तावित प्रतिरूप की प्रकृति को स्पष्ट करने और दूसरे (GW170817) के स्थान को (बाध्य करने) रोकने में भी मदद की है। (दीपांकर भट्टाचार्य, शबनम इय्यानी, विदुषी शर्मा, अजय विभूति, वरुण भालेराव एवं सहयोगी)

अतिवेधी एक्स-रे ध्रुवीकरण का मापन

CZTI उपकरण 100 से 400 keV की ऊर्जा सीमा में एक्स-रे उत्सर्जन के ध्रुवीकरण को मापने की अद्वितीय क्षमता का दावा करता है। इसका उपयोग क्रैब पल्सर से विकिरण के ध्रुवीकरण को मापने के लिए किया गया है - एक छोटा, पृथक, तीव्र-चक्रण (अवधि 33 मिलीसेकंड), सशक्त चुम्बकीय (~ 3 टेरागॉस) न्यूट्रॉन स्टार प्रचुर मात्रा में मैग्नेटोस्फीयर उत्सर्जन पैदा करते हैं। प्राप्त नतीजों से पता चलता है कि सभी पल्स चरणों में ध्रुवीकरण की कोणीय स्थिति उचित ढंग से आकाश में पल्सर के चक्रण अक्ष के प्रक्षेपण के साथ पंक्तिबद्ध है, और यह, यह भी बताता है कि इस उत्सर्जन का बड़ी तादाद में भूमध्यरेखीय पल्सर वायु क्षेत्र में जो बंद मैग्नेटोस्फीयर है, उसके ठीक बाहर उत्पन्न होता है। प्राप्त नतीजों से पता चलता है कि सभी पल्स चरणों में ध्रुवीकरण की कोणीय स्थिति उचित ढंग से आकाश में पल्सर के चक्रण अक्ष के प्रक्षेपण के साथ पंक्तिबद्ध है, और यह, यह भी बताता है कि इस उत्सर्जन का बड़ी



क्रैब पल्सर के ध्रुवीकरण का एस्ट्रोसैट मापन। वामावर्ती छवि - जहां एक ओर पैनल- a ,में रंगीन पट्टियाँ ध्रुवीकरण की डिग्री दिखाती हैं वहीं दूसरी ओर पैनल -b , उन स्थिति कोण के पल्स फेज के फंक्शन के प्रकार्य को दर्शाता है। स्पष्टता के लिए , इसमें पल्स की दो अवधियों को दिखाया गया है। पतली काली रेखा द्वारा पल्स प्रोफ़ाइल को दर्शाया गया। दक्षिणावर्ती छवि - रंगीन (ऐरो)संकेत आकाश के तल में ध्रुवीकरण वेक्टर को दर्शाते हैं, जोकि क्रैब नेबुला के मध्य भाग की एक चंद्र एक्स-रे वेधशाला (नासा) की छवि पर अध्यारोपित है। रंग-संकेत वामावर्ती आंकड़े में दिखाए गए चरण पर्वतमाला से मेल खाता है। सफेद (ऐरो)संकेत पल्सर के स्पिन अक्ष के प्रक्षेपण का प्रतिनिधित्व करता है। (साभार: संतोष वडावले एवं सहयोगी)

तादाद में भूमध्यरेखीय पल्सर वायु क्षेत्र में जो बंद मैग्नेटोस्फीयर है, उसके ठीक बाहर उत्पन्न होता है। कई चमकीली गामा किरणों के विस्फोटन हेतु भी ध्रुवीकरण को मापा गया है, जिसमें दर्शाया गया है कि ध्रुवीकरण गुणस्वभाव किस प्रकार से विस्फोट के माध्यम से तीव्रता से परिवर्तित होते हैं। यद्यपि विस्फोट के छोटे वर्गों को दृढ़ता से ध्रुवीकृत किया जा सकता है, किन्तु वहीं इसके सम्पूर्ण विस्फोटन से औसत ध्रुवीकरण कम हो जाता है। इस बार समाधित ध्रुवणमापन जोकि बहु-लक्ष्यों के साथ स्पेक्ट्रोस्कोपी से युग्मित है, उसने तीव्र गामा-किरणों के उत्सर्जन -तंत्र में एक गहरी अंतर्दृष्टि प्रदान की है। जो प्रकाशिकी प्रक्रियाओं के क्रमिक विकास को प्रदर्शित करने के लिए वैकल्पिक रूप से बारीक़ सिंक्रोट्रॉन को दर्शाता है , जिसका उत्सर्जन क्रमित चुंबकीय क्षेत्र में होता हैं। (शबनम इय्यानी, विदुषी शर्मा, दीपांकर भट्टाचार्य एवं सहयोगी)

एस्ट्रोसैट उपयोगकर्ताओं हेतु सहायता

एस्ट्रोसैट से जुड़ी प्रमुख गतिविधियों में से जो एक है, वो इसके उपयोगकर्ताओं को सहायता एवं सहयोग प्रदान करना है, जिसमें आयुका शामिल है। इस उद्देश्य हेतु, इसरो से प्राप्त आर्थिक सहयोग के ज़रिये आयुका एस्ट्रोसैट के वैज्ञानिक सहायता प्रकोष्ठ (ASSC)का संचालन कर रहा है। एस्ट्रोसैट कार्यप्रवाह संचालनों के केंद्र में एस्ट्रोसैट प्रपोज़ल प्रोसेसिंग सिस्टम नामक एक प्रौद्योगिकी - पैकेज है जो उपयोगकर्ताओं से अवलोकन प्रस्ताव प्राप्त करता है और समीक्षा, समय आबंटन , उपकरण समाकृति का प्रबंधन करता है और अंततः उपग्रह को चलाने वाले अदेशानुपालन इनपुट का संचालन करता है। इस पैकेज का रख-रखाव और अद्यतन ASSC द्वारा किया जाता है। एस्ट्रोसैट के सभी उपकरणों से आँकड़ों को कम करने और विश्लेषण हेतु यह प्रकोष्ठ एक कंप्यूटिंग वातावरण भी प्रदान करता है, जिसे इसके सभी उपयोगकर्ताओं को उपलब्ध कराया गया है। ASSC एस्ट्रोसैट प्रस्तावों के अवलोकन के साथ-साथ उत्पन्न आंकड़ों के उपयोग में उपयोगकर्ताओं को प्रशिक्षित करने के लिए नियमित कार्यशालाओं का आयोजन करता है। प्रकोष्ठ, एक एस्ट्रोसैट हेल्प डेस्क भी चलाता है जिसके माध्यम से उपयोगकर्ताओं से प्राप्त सभी प्रश्नों को संबोधित किया जाता है। ASSC के वेब पोर्टल को सभी आवश्यक सूचनाओं, प्रशिक्षण सामग्री और सॉफ्टवेयर के प्रचार-प्रसार के साथ-साथ कई ऑन-लाइन टूल्स और उपयोगिताओं के परिचारक के रूप में भी स्थापित किया गया है। ASSC 42 देशों में फैले लगभग 1400 अनुसन्धानकर्ताओं के कुल पंजीकृत एस्ट्रोसैट उपयोगकर्ताओं के आधार का कार्य करता है, जिनमें से लगभग आधे भारत से और प्रमुखतः विश्वविद्यालय क्षेत्र से है।

AtroSat Journey 2015 - 2020

Five Years of AstroSat

The Indian multi-wavelength Space Astronomy Mission, AstroSat completed five years in orbit on 28 September 2020. IUCAA has been deeply involved in this mission from the stage of conception, through realisation and subsequent utilisation. The Ultra Violet Imaging Telescope, on board AstroSat was led by Shyam N. Tandon of IUCAA. After the launch, IUCAA, with financial support from ISRO, has taken on the responsibility to run the AstroSat Science Support Cell to provide help, support and training to AstroSat users throughout India and abroad. IUCAA also runs the Payload Operation Centre for one of the on-board instruments, the Cadmium Zinc Telluride Imager.

Over the course of these five years, members of IUCAA have pursued a wide variety of science goals with AstroSat. In this activity, they have been collaborating actively with research scholars and faculty from many Colleges and Universities including SP Pune University, Jamia Millia Islamia, IIT Kanpur, IIT Bombay, Christ (Deemed to be) University, Tezpur University, Pacific University, IISER Mohali, IISER Pune, Mahatma Gandhi University, RJ College Mumbai and several others. Some of the highlights of these research are presented below.

Stars and Galaxies

One of the key strengths of AstroSat has been the excellent imaging capability of its Ultra Violet Imaging Telescope (UVIT). This has enabled AstroSat to obtain both deeper and sharper images of cosmic objects in UV band than ever before, for a wide field of size about half a degree. Ultraviolet light in Lyman continuum band is the main source of ionisation of the intergalactic medium. Kanak Saha, Shyam Tandon and collaborators (2020) used AstroSat UVIT to discover the farthest known galaxy (at redshift z=1.42) that is releasing a copious amount of Lyman continuum radiation into its surroundings. This galaxy has been christened AUDFs01 (AstroSat Ultra Deep Field source 01), and it demonstrates the vital role that galaxies have played in keeping the diffuse intergalactic gas highly ionised.

Detailed UV imaging of nearby galaxies has revealed the sites of recent star formation and some of them are in surprising, unlikely places - such as outskirts of lonely, gas poor galaxies (for example, NGC 4571: Kanak Saha and Shyam Tandon), and in gas streams stripped from "Jellyfish" Galaxies (Shyam Tandon and collaborators - George et al 2018). The UVIT study of globular star clusters, some of the oldest objects in our Galaxy, has revealed interesting facts about their evolution. For example, it has been found through the study of UV colour-magnitude diagram that the cluster NGC 1851 was formed by the merger of multiple star clusters of ages differing by over 3 billion years (Shyam Tandon and collaborators - Subramaniam et al 2017).

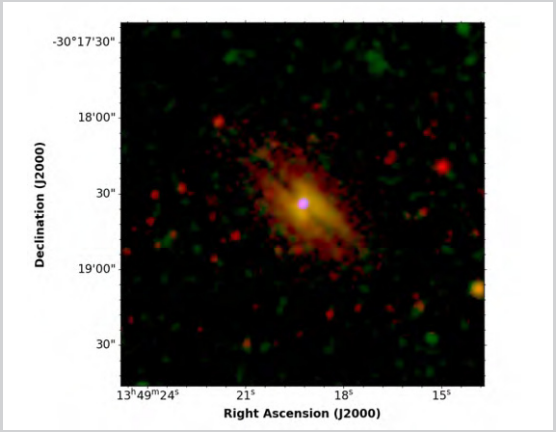
Active Galaxies

The UVIT, together with other X-ray instruments - Soft X-ray Telescope (SXT), Large Area X-ray Proportional Counter (LAXPC) and Cadmium Zinc Telluride Imager (CZTI) on-board AstroSat provides a unique capability of simultaneously observing a cosmic source over a very wide energy band. This capability is particularly important for studying objects whose radiation intensity varies significantly and rapidly over time. One such class of objects is Active Galaxies, where a central super massive (a million to a billion times the mass of the sun) Black Hole, fed by the surrounding gas and stars, glow brightly at all these wavebands and also produce powerful jet-like matter ejection which further contributes to the observed emission. Scientists at IUCAA are carrying out observations of several Active Galaxies with AstroSat (Gulab Dewangan, Ranjeev Misra, Savithri Ezhikode, Prakash Tripathi, and Zahir Shah). One such example is the Seyfert-1 galaxy IC4329A. The spectrum observed in the ultraviolet band has provided the evidence for an accretion disk, a thin, differentially rotating entity through which material approaches the Black Hole. Contrary to the expectations, however, this

disk is found to be truncated at a relatively large distance (80-150 Gravitational radii) from the Black Hole. The inner part of the flow does not follow this disk structure any more. Careful comparison of the simultaneous data from the UVIT, SXT and LAXPC has also revealed important aspects of how the observed emission originates.

The spectral slope in the X-ray band and the soft X-ray excess flux are both found to be varying in step with the UV radiation. This is a tell-tale sign of the X-ray emission being produced as a result of Compton up-scattering of ultraviolet photons generated in the accretion disk.

AstroSat observation of a jet-dominated Active Galaxy has revealed that the broad band X-ray spectrum significantly deviates from a power-law shape, which along with the UVIT data, has important implications on the nature of the underlying particle distribution that produces the emission.



Composite AstroSat/UVIT NUV (red), FUV (green) and Chandra X-ray (blue) image of IC4329A. The unresolved active nucleus is clearly seen in the X-rays and NUV but it is not detected in the FUV band due to heavy extinction by the dust lane passing through the central regions. (Credit: Gulab Dewangan)

Black Hole X-ray Binary Systems

One of the main themes being pursued by AstroSat X-ray instruments is the rich patterns of intensity variations produced by compact objects, including Neutron Stars and Black Holes. Stellar Mass Black Holes accreting mass from a binary companion are of particular interest, as in these objects the radiating matter enters the deepest of gravitational potential wells and strongly experiences the effects of general relativity. The resulting intensity variations and spectral shapes can be used to infer the properties of the black hole including its mass and spin, and they can also reveal the hydrodynamic processes in the accretion flow. AstroSat's capability of carrying out sensitive timing analysis at high energy X-rays is a perfect tool to explore the innermost regions of the flow. A number of Stellar Mass Black Hole binary systems have been studied by IUCAA members with AstroSat. The list includes Cyg X-1, Cyg X-3, GRS 1915+105, MAXI J1820+070, Swift J1535-671, 4U1630-47, Swift J1658.2-4242 to name a few. In many of these cases, comparison of the variability at low energy and high energy X-rays has enriched our knowledge of the inner regions of the accretion flow and the causes of flux variability. For example, it could be inferred that the broadband noise component of the variability arises due to perturbations originating in the outer parts of the accretion disk migrating inwards. Some of the observed variability has been of quasi-periodic, oscillatory nature (QPO). The frequency of the QPO is often found to be correlated with the X-ray flux. In particular Swift J1535-571 exhibited an extremely tight correlation between the QPO frequency and the slope of the high-energy X-ray spectrum, suggesting the involvement of a Comptonising cloud.

A detailed study of the energy-dependent temporal behaviour of the QPOs observed in the Black Hole system Swift J1658.2-4242 could be explained by the variation in the temperature of the accretion disk and a hot corona overlying it, with a time lag between them. In the system GRS 1915+105, a 70-Hz QPO which so far was thought to occur at a fixed frequency, was found by AstroSat to have a variable frequency correlated with the spectral state of the system. Another QPO in this system, that occurs in the range 2 to 6 Hz, was found, via the analysis of the broadband AstroSat spectra, to vary exactly as the dynamical frequency, defined as the inverse of the sound crossing time through the disk. This measurement also suggested that this black hole is spinning at nearly 90% of its maximum possible rotation. A coordinated spectral study with AstroSat, MAXI and the Chandra Observatory found a fast spinning Black Hole also in the system 4U1630-47. These observations also detected a fast moving (about 350 km/s) ionised wind from the system. (Ranjeev Misra, Dipankar Bhattacharya, Yash Bhargava, V. Jithesh, Bari Maqbool, Zahir Shah, Mayukh Pahari, and collaborators)

Accreting Neutron Stars

Another important class of compact objects being studied by AstroSat consists of Neutron Stars, which distinguish themselves by their extremely strong magnetic fields, covering the range giga- to tera- gauss and beyond. Accretion onto neutron stars is thus subjected to strong hydromagnetic effects that imprint their own signature on the intensity variations and the spectrum. In some systems, the spin of the neutron star can also manifest itself in periodic modulation of observed flux; such objects are called accreting X-Ray Pulsars. Rich temporal behaviour of the Neutron Star Low-mass X-Ray Binary 4U1728-34 was studied with AstroSat, demonstrating a ~820-Hz QPO, thermonuclear X-Ray Bursts and a periodic intensity variation at 363Hz, identified with the spin frequency of the neutron star, during one such X-Ray Burst. AstroSat also observed a bright X-Ray outburst of the High Mass X-Ray Binary Neutron Star system 4U0115+63 in detail and discovered QPOs at 1 and 2 millihertz that arise in the interaction of the inflowing matter with the strong magnetic field of the Neutron Star. The magnetic field manifests itself also in the X-Ray spectrum in the form of Cyclotron Resonance Scattering Features - absorption-like dips whose energy values are directly related to the field strength. One such system, Her X-1, has been known to show a secular variation of the energy of the cyclotron feature, suggesting a gradual change in the field strength in the emission region. IUCAA members have followed this system with multiple AstroSat observations combined with other data, and have discovered that over the past two decades the apparent field strength of this system gradually reduced over the first 15 years and has since then assumed a steady value. This was explained as a mound of accreted matter gradually building up at the magnetic pole over time, and reaching a steady maximum height at which the matter inflow and outflow balance each other.
(Jayashree Roy, Suman Bala, Dipankar Bhattacharya, Ranjeev Misra, and collaborators)

Gamma Ray Bursts

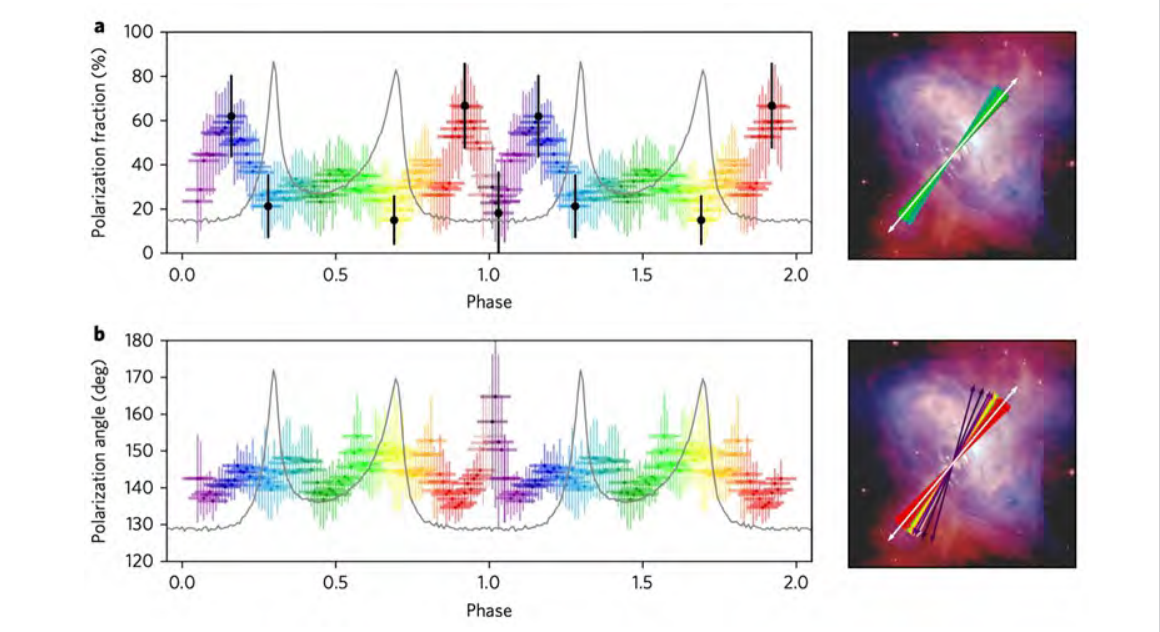
The Cadmium Zinc Telluride Imager payload on AstroSat has been a prolific detector of Gamma Ray Bursts (GRB) The first burst was detected within hours of it being switched on, and the total count in five years of operation has reached over 250 detections. The entire data processing and analysis of all these GRBs take place at the payload operation centre located at IUCAA, and the information regarding any detection is immediately posted in the public domain. Apart from facilitating multi-band study of the prompt emission of GRBs, CZTI has also helped in clarifying the nature of a proposed counterpart of a Gravitational Wave event (GW170104) and in constraining the location of another (Gw170817).
(Dipankar Bhattacharya, Shabnam Iyyani, Vidushi Sharma, Ajay Vibhute, and collaborators)

AstroSat User Support

One of the key activities related to AstroSat that IUCAA is involved in is the help and support provided to the users of AstroSat. The AstroSat Science Support Cell (ASSC) is being run by IUCAA for this purpose with financial support from ISRO. At the heart of AstroSat operations workflow is an IT package called the AstroSat Proposal Processing System which receives observing proposals from the users, manages reviews, time allocation, instrument configuration and eventually produces inputs for the generation of commands that run the satellite. This package is maintained and updated by the ASSC. The Cell also provides a computing environment to reduce and analyse data from all instruments of AstroSat, which is made available to the users. ASSC conducts regular workshops to train users in making AstroSat observing proposals as well as in utilising the data generated. The Cell also runs the AstroSat help desk that addresses all the queries received from users. The web portal of the ASSC is set up to disseminate all the necessary information, training material and software, as well as to host several on-line tools and utilities. The ASSC serves the entire registered AstroSat user base of nearly 1400 researchers spread over 42 countries, about half of which is from India and primarily from the University sector.

Hard X-Ray Polarisation Measurements

The CZTI instrument boasts the unique capability of measuring the polarisation of X-Ray emission in the energy range of 100 to 400 keV. This has been used to measure the polarisation of the radiation from Crab pulsar — a young, isolated, fast-spinning (period 33 milliseconds), strongly magnetised (~3 teragauss) neutron star generating copious magnetospheric emission. The results show that in all pulse phases the polarisation position angle is well lined up with the projection of the spin axis of the pulsar in the sky, suggesting that the bulk of this emission is generated in the equatorial pulsar wind region just outside the closed magnetosphere. Polarisation has also been measured for several bright gamma ray bursts, showing that the polarisation properties change quickly through the burst. While small sections of the burst may be strongly polarised, the average polarisation over the entire burst tends to be low. This time-resolved polarimetry, coupled with spectroscopy from multiple missions, has provided deep insight into the mechanism of the prompt gamma-ray emission — showing evolution from photospheric processes to optically thin synchrotron emission occurring in significantly ordered magnetic fields.
(Shabnam Iyyani, Vidushi Sharma, Dipankar Bhattacharya, and collaborators)



AstroSat measurement of the polarisation of the Crab pulsar. Left hand figures: coloured bars in panel a show the degree of polarisation and those in panel b the position angle, as a function of pulse phase. For clarity two periods of the pulse are shown. The thin black line shows the pulse profile. Right hand figures: coloured arrows display the polarisation vectors in the plane of the sky, superposed on a Chandra X-Ray Observatory (NASA) image of the central part of the Crab Nebula. The colour code corresponds to that of the phase ranges shown in the left figures. The white arrow represents the projection of the pulsar's spin axis. (Credit: Santosh Vadawale and collaborators)

IUCAA IN NEWS

IUCAA IN NEWS

Sakal Times

SPPU, IUCAA sign MoU for research

ST CORRESPONDENT
reporters@sakaaltimes.com

PUNE: Savitribai Phule Pune University (SPPU) and the Inter-University Centre for Astronomy and Astrophysics (IUCAA) have signed a Memorandum of Understanding (MoU) for carrying out collaborative research development and teaching programmes in Physics, Astronomy, Astrophysics, Space Sciences, Atmospheric Sciences, Instrumentation, Technology and other areas. The IUCAA is leading in contributing to a number of mega-science programmes like the Thirty Metre Telescope (TMT), Laser Interferometric Gravitational Wave Observatory (LIGO), Square Kilometre Array (SKA) and Aditya-L1 etc. while the faculty is also involved in a number of projects including a wide variety of national and international

The roadmap of this collaboration will be charted by an apex committee involving senior leadership of both the institutes.

toral fellows of IUCAA and SPPU. The research and interactive spaces will be created at both the SPPU and IUCAA premises. One of the major objectives of this MoU is to identify and establish jointly taught courses at post-graduate and research level lead- /MTech/PhD and and IUCAA will jointly establish laboratory infrastructure to carry out advanced interdisciplinary research and instrumentation in areas of mutual interest. These laboratories will also be used to impart practical training to the students and researchers of both SPPU and IUCAA.

The current thrust areas

sakaltimes.com | Saturday, February 29, 2020 CITY/NATION

Scientists address students' curiosity

MANASI SARAF JOSHI
@GargiManasi

PUNE: As the National Science Day this year has the theme of 'Women in Science', renowned scientist **Jayant Naralikar** narrated how he and his mathematician wife helped their three daughters in tackling science. Naralikar said he and his wife did not take deliberate efforts but just encouraged their daughters to ask questions.

NAT'L SCIENCE DAY

He was interacting with the students on the occasion of National Science Day at Inter-University Centre for Astronomy and Astrophysics (IUCAA) along with IUCAA Director Somak Raychaudhury, scientists Anupam



SHOWCASING TALENT: Muktangan School held an exploratory exhibition on the occasion of National Science Day on Friday. KALPESH NUKTE



RAPT: Students visiting Inter-University Centre for Astronomy and Astrophysics (IUCAA) paying keen attention to a lecture by an expert. ANAND CHAINI

Rani Madhav Khandare asking how do we have different colours of stars in our sky?

To which Naralikar said, "The colour

creasing temperature order."

"I don't know how many stars are of red or blue colour

ing them, you will find one galaxy per minute

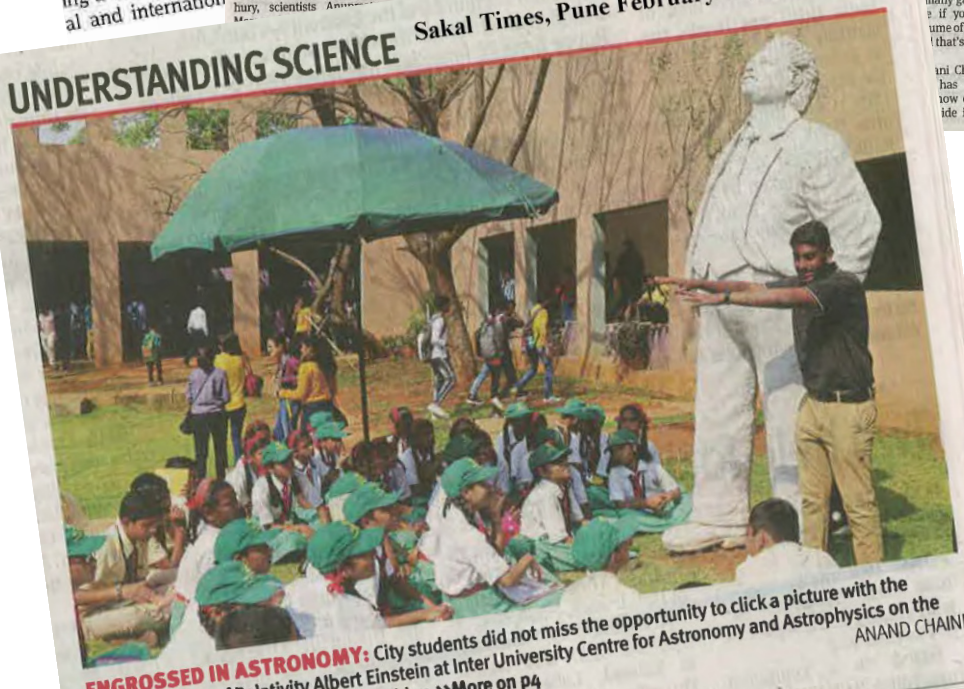
graph of galaxies xies certain mass or his gives you some distribution. Then, polate that and find many galaxies there if you have the ume of the universe that's how you es-

ni Chavan asked has reached the ow do we know ide it? Naralikar said, "If we make a model of the Sun and then test it, the Sun emits Neutrino and by studying the condition and its volume, we can know about what would be the temperature at the centre of the sun."

There were many other questions including what could be done to set up a science centre in the rural area, how after the Big Bang, the dark age and many others.

Sakal Times, Pune February 29, 2020 P. 1

UNDERSTANDING SCIENCE



ENGROSSED IN ASTRONOMY: City students did not miss the opportunity to click a picture with the statue of Father of Relativity Albert Einstein at Inter University Centre for Astronomy and Astrophysics on the occasion of National Science Day on Friday. >>More on p4 ANAND CHAINI

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SPPU, IUCAA i joint space, as

The laboratory, called SITARA, wi

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Astrosat and is presently working on a payload for Aaditya L1 mission to the Sun, both missions taken up in collaboration with the Indian Space Research Organisation (ISRO).

"This is an unique collaboration with so many departments of SPPU. It will an experimental initiative where the lab will operate both as a training and research centre. Students and faculty from both institutions will initially work on LIGO, along with some space projects. We are also considering starting a new master's level programme that will focus on training meant for these research activities," said IUCAA Director Somak Raychaudhury.

In the long-term, the collaborating institutions plan to set up a payload integration centre at SITARA. The idea is to train and guide college students and others, outside ISRO, who build nano-satellites. However, the plan of this centre is at a nascent stage and requires several approvals, said officials.

Commenting on the collab-



Last week, the two instit programmes and space-

Now, S quicker proble

EXPRESS NEWS SERVICE
PUNE, OCTOBER 7

STUDENTS OF Savit Phule Pune University (will soon be able to re complaints related to and campus infrastru such as electrical and p ing issues besides intern mobile network proble an app that promises to quicker solutions.

The SPPU, on Mo launched a dedicated ap tion where students can ter problems and chec concerned teams to get sues resolved at the ea Students can use thi through the user nam vided to them by the univ

The web-based *helpdesk.unipune.acin*, ha configured by SPPU's Edu Foundation, a company

oration, SPPU Vice Chanc Nitin Karmalkar said, "The has a number of bright stud who need to take up cours meet present-day challe

The Indian EXPRESS epaper editions Tue, 08 October 2019 epaper.indianexpress.com/

Had no doubt that Abhijit Banerjee would get Nobel Prize: Friend, IUCAA director

ANURADHA MASCARENHAS
PUNE, OCTOBER 14

"THERE WAS no doubt in my mind that Abhijit Banerjee would get the Nobel prize," Professor Somak Raychaudhury, director of Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, who has had a long association with the Nobel Prize-winning economist said Monday.

An Indian-American, Abhijit Banerjee, along with Esther Duflo and Michael Kremer won the 2019 Nobel Prize for economics "for their new approach to obtain reliable answers about the best way to fight global poverty.

In a tweet on Monday, Professor Raychaudhury wrote, "...it was long being Abhijit Banerjee (the) President..."





AP/PTI

Professor Somak Raychaudhury and Nobel Prize-winning economist Abhijit Banerjee

varies from country to country," the IUCAA director said.

"It is interesting that how he (Banerjee) looks at economics is similar to the way we look at physics and astronomy — we have had lot of discussions of that sort — he is technically extremely competent in terms of the tools of science," Prof Raychaudhury elaborated. Going down memory lane, the IUCAA director recalled the time when Banerjee and he were studying at Presidency College. "He was my senior and was studying economics, while I was studying physics. His father, the famous Prof [illegible], was the 200-year-old Presidency College into a university. Banerjee was part of the mentor group that was headed by Amartya Sen (Indian economist, who was awarded the 1998 Nobel prize in economic sciences). Famous people from various subjects all over the world came together to mentor this University and Banerjee told me that he wanted me to be the head of physics group. "I came to India and we worked together for three years. I was dean of the University and he was part of the mentor group that [illegible]

...naugurate lab for ...tronomy projects

...ill provide research and training options



...tutions had inked an MoU to jointly undertake new courses, research ...-based activities. *Express*

...PPU students can find ...r solutions to infra ...ms through new app

the university. In the initial phase, the app will cater to infrastructure-related issues in hostels or at other locations on the campus.

With this app, university officials are hopeful of bringing in transparency and allow students to track the complaint," said Zunjar Bhamre, IT manager at SPPU.

Asked about the time period it will take to fix a registered complaint, Bhamre said, "Once

Times of India, Pune February 29, 2020 P.4

SPPU student gets award for animal-free pharma test story

Ardhra.Nair@timesgroup.com

Pune: Savitribai Phule Pune University's Joyita Sarkar was one of the 21 people and the only one from an educational institute in the state to be awarded by President Ramnath Kovind for her role in science communication and popularisation on the National Science Day in New Delhi on Friday.

She received 'Augmenting Writing Skills for Articulating Research' (AWSAR) award for her science story, 'Coming soon: Animal model-free system for Pharmaceutical Testing', which she penned as a postdoctoral research fellow of the SPPU's physics department. Since January this year, she has been working as an assistant professor at the Institute of Chemical Technology's Marathwada campus.

"It was a great and motivational experience to receive [illegible] award [illegible] hical and results are sometimes erroneous because despite having similar systems, we are different from them.

"In today's day and age, when we are so aware of animal rights, using them for testing a drug that will be used by humans, is wrong. So, multiple research works are going on to build a system which can effectively test medicines that can then be used by humans."

Sarkar turned this into a story about an imaginary world where all the animals are free and happy in the wild. "The copyright of the story belongs to DST," she said.



Mandar Deshpande

School students and science lovers visit the Inter-University Centre for Astronomy and Astrophysics (IUCAA) on National Science Day on Friday

Scientist Raghunath Mashelkar urges people to have trust in new startups

Pimpri Chinchwad: Eminent scientist Raghunath Mashelkar on Friday stressed the need for people to have trust in new startups and urged industrialists to give the youth a chance.

"India's problem is not budget deficit but trust deficit," he said in his keynote address during the inauguration of the two-day Festival of Future held by the Pimpri Chinchwad Municipal Corporation at Autocluster in Chinchwad.

Civic chief Shravan Hardikar said, "We want the youth to come up with ideas about automobile and industrial sectors thriving in Pimpri Chinchwad, Chakan, Indapur and Baramati, bio-technology, urban spaces, manufacturing, education, art and food." TNN

NATIONAL SCIENCE DAY



SIR ISAAC NEWTON & HIS APPLE

Students attend an exhibition at IUCAA on the National Science Day, in Pune on Friday. *Arul Horizon*

Indian Expres, Pune February 29, 2020 Newsline P.1

IUCAA IN NEWS

Sakal Times

Is it a dawn of new era in BLACK HOLES?

MANASI SARAF JOSHI
@GargiManasi

April 10, 2019 was one of the important days for the scientist community across the world. On this day, the quest for over two decades ended after nearly 200 scientists from Event Horizon Telescope (EHT) were successful in capturing the first ever image of a black hole.

A black hole is a mysterious place in space with such enormous mass and extreme gravity that nothing can escape it. Not even light. As light does not get out, black holes are invisible and thus get their name.

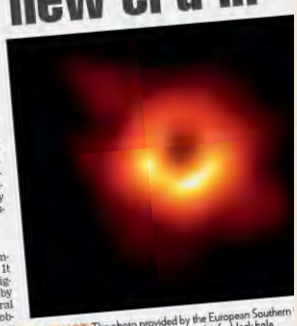
Dr Katherine Bouman, a 29 year-old post-doctoral fellow at Massachusetts Institute of Technology (MIT), received appreciation across the world for being instrumental in creating of the algorithm that helped produce this image.

"The image will not only throw open new research [illegible] but also opens up will also be able to learn about how these black holes grow, how they can launch jets of material which shapes the formation and evolution of galaxies," said Surhud More, scientist working at Inter-University for Astronomy and Astrophysics (IUCAA).

The importance

This first image is for entire humanity to remember. It gives us a glimpse of the enigmatic black holes predicted by Einstein's theory of general relativity. Until these new observation were made, we knew about black holes indirectly (for example, via their gravitational effects on stars, or the emission coming from the gas swirling a lot further around it, or through gravitational waves from mergers), Surhud added.

But nobody had the resolution needed to see what the edge of a black hole really looks like. Of course, by definition no one can see exactly what is inside a black hole, and this image does not really tell us what is inside the black hole. It captures the light which just manages to skirt the black hole



THE SHOT: The photo provided by the European Southern on Wednesday shows the first photograph of a black hole.

idea of what it means for photons to go around a black hole: if you are at the photon radius of the black hole, then the light bouncing from the back of your head, can go around the black hole and travel towards the front.

This light travelling around the black hole will allow you to see the back of your head, he elaborated.

The size of this photon radius and this phenomenon is predicted by Einstein's theory

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Hindustan Times, Pune Feb.29, 2020 P.2

MISSION SCIENCE TAKES LABORATORY, EXPERIMENT AND LEARI





- Left: Students across various age groups get a close look at a satellite at IUCAA at the SPPU, on the occasion of Science day on Friday. MILIND SAURKAR/HT PHOTO
- Top: The Science Park in Chinchwad saw students display a host of exhibits, which then drew the wrapt attention of students and families visiting the show. HT PHOTO



VIDYASAGAR DAUD OF PUNE SUGGESTED 'SANTAMASA', ANANYO BHATTACHARYA OF SURAT SUG

IAU picks names suggested by Pune boy, Surat you

EXPRESS NEWS SERVICE
PUNE, DECEMBER 17

THE INTERNATIONAL Astronomical Union has selected names suggested by Indian youngsters, including a 13 year old from Pune — Vidyasagar Daud, a Class 8 student of Sinhagad Springdale Public School — for the star catalogued as HD 86081 and its exoplanet HD86081b.

Twenty-year-old Ananyo Bhattacharya from Sardar Vallabhbhai National Institute of Technology, Surat, proposed the name 'Bibha' (which is the Bengali pronunciation of the Sanskrit word 'Vibha' and means "a bright beam of light") while Daud from Pune proposed 'Santamasa', which means 'clouded' in Sanskrit and is analogous to the nature of the exoplanet's atmosphere.

Astronomers have discovered over 4,000 planets orbiting other stars called exoplanets. While astronomers catalogue their new discoveries using telephone-number-like designations, there has been growing interest among astronomers and the public in also assigning proper names, as is done for Solar System bodies. The International Astronomical Union is the authority responsi-



Vidyasagar Daud

ble for assigning official designations and names to celestial bodies. It is celebrating 100 years of fostering international collaboration (IAU100) in 2019.

The IAU100 NameExoWorlds project saw widespread participation around the world. In India, a contest called "Name ExoWorlds India" was launched on July 10, 2019 by the national committee working on this in association with the

Astronom [illegible] had invit [illegible] for the e [illegible] and its pa [illegible] and colleg

Lying [illegible] away, HD [illegible] ter, larger [illegible] Its expl [illegible] lonely wo [illegible] star. It ap [illegible] the planet [illegible] ment is

MASCARENHAS
PUNE, APRIL 19

REVANTA SARABHAI, who is among the handful of well-known male Bharatnatyam dancers in India, believes that staying true to the classical dance form is important as "the vocabulary of this dance style is versatile enough to tell any kind of story".

The grandson of eminent physicist Dr Vikram Sarabhai and legendary classical dancer Mrinalini Sarabhai, Revanta is trying to tell new stories about tionships, through this 3000-year-old art form.

To mark the 100th birth anniversary of Mrinalini Sarabhai, he is now taking his message to cities across India, where he will present Bharatnatyam performances with a unique new repertoire, comprising the traditional and the modern. "It is an ode to my grandmother and my first guru," Revanta tells *The Indian Express*.

After a performance at Bengaluru in February, Revanta, along with his wife Priyanka Raja, is in Pune for his sented a Bharatnatyam performance with the theme 'From cosmic dance to climate change' at the Nehru auditorium in the city. The event was organised by the India House Art Gallery.

He says it's important to reach out to a younger audience. "One needs to package the content for a younger audience, not by mixing Bollywood music with the dance form but by exploring modern themes that are relevant today," says Revanta.

"For instance, today's 21st



Revanta Sarabhai performs in Pune. *Pavan Khengre*

nerability. In one of the pieces, I am telling a modern day love story of a man whose girlfriend is abroad and how they have to rely on fragmented digital communication to connect. The way we love has changed so much. Today it is technology driven, unlike the traditional love songs that would be portrayed by showing nature, birds, brooks and more. The gender stereotypes are so ingrained in the traditional repertoire that I have twisted the gender roles, saying times have changed and the woman is no

The Indian EXPRESS epaper editions Sat, 20 April 2019 epaper.indianexpress.com/c/38675634

NING TO THE MASSES





Pulastya science festival to be held at IUCAA from November 6-8

EXPRESS NEWS SERVICE
PUNE, NOVEMBER 4

IN THE birth centenary year of iconic Marathi writer and humorist P L Deshpande, who was engaged in a public outreach programme of the Inter University Centre for Astronomy and

P L Deshpande was one of the visionaries behind IUCAA's science centre, which is also known as Muktangan Vidnyan Shodhika. Fondly called Pu La, the building at IUCAA is named 'Pulastya' after

nitrogen will be held at the event.

According to science centre coordinators at IUCAA, several talks have been arranged to also explain to children how to view

PRINCIPAL SCIENTIFIC ADVISOR K VIJAYRAGHAVAN IN CITY

'Pune intellectual fountainhead of nation, has self esteem & courage'

EXPRESS NEWS SERVICE
PUNE, SEPTEMBER 19

PUNE HAS been the intellectual fountainhead of the country for a long time and the city's vibrancy and enthusiasm, apart from the many national institutions here, are among the key reasons behind selecting the city for a science and technology 'Knowledge Cluster', Professor K VijayRaghavan, principal scientific advisor (PSA) to the Union ment, said on Thursday. he city to attend a Town neeting at the Inter city Centre for Astronomy

'There is no single weak link, several need to be strengthened'

Principal Scientific Advisor to the Union government, Prof K VijayRaghavan, said many institutions faced problems and complex issues, while responding to queries on the delay in giving stipends to research students. "Top institutions have these issues and at the smaller ones, it goes to a deeper level. We are addressing these issues but the proposed Knowledge Cluster will not solve it," he said, adding that when each case was examined deeply, it was found that multiple elements needed to be addressed.

"Sadly, there is no single weak link. Every link needs to be strengthened. Maybe all are not doing well at the level of institutions... some institutions do a terrific job and some do not...," he said.

GESTED 'BIBHA'

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Jupiter in size, a state-
sued by the Inter

University Centre for Astronomy and Astrophysics said.

Samir Dhurde, from IAU National Outreach for India, said Indian youngsters responded to this unique opportunity to find out more about astronomy, these breathtaking exoworlds and also were able to help establish an Indian name in the sky.

Dr Somak Raychaudhury, Director, IUCAA, and member of the national committee, said, "This large-scale election procedure has come up with the best name possible. Apart from the literal meaning of the word, which is appropriate, the star's name refers to the pioneering Indian woman scientist Dr Bibha Choudhury. She discovered a new subatomic particle, the pi-meson, from experiments in Darjeeling, with her mentor D M Bose and published her results in *Nature*, but did not get due recognition."

PUNE

ISRO missions draw biggest crowds at science institutes

ANJALI MARAR
PUNE, FEBRUARY 28

EXHIBITS AND models of ISRO's missions Chandrayaan-2 and Aditya-L1 were the biggest draw for residents of Pune on the National Science Day on Friday.

Crowds of children and their families thronged the Inter-University Centre for Astronomy and Astrophysics (IUCAA), India Meteorological Department (IMD), National Centre for Cell Science (NCCS), Agharkar Research Institute (ARI), Indian Institute of Tropical Meteorology (IITM) and scientific departments at Savitribai Phule Pune University (SPPU), where most scientific displays highlighted India's latest contributions in the fields of space, biotechnology, astronomy, chemistry and defence, among others.



At an exhibition organised at Agharkar Research Institute on Friday. *Ashish Kale*

The Chandrayaan-2, Laser Interferometer Gravitational-wave Observatory (LIGO) and Manav Human Atlas programme were among the major attractions, besides some of the upcoming missions and projects like Thirty Metre Telescope (TMT) and Aditya L1 mission.

However, the maximum crowds were drawn towards the Chandrayaan-2 and Aditya-L1 missions with youngesters enthusiastically posing for photographs with the model of the GSLV Mark III rocket, which was placed near Bhaskara Hall at IUCAA.

The Vikram lander and Pragyan rover, launched as part of the Chandrayaan-2 mission in September last year, had failed to execute a soft landing on the Moon. But this was no deterrent for the crowds who were seen waiting patiently for the maiden simulation-based film screening, which focused on the launch Chandrayaan-2. Presented in Marathi and English by UK-based research scholar John Paice, visitors of all age groups witnessed the simulation-controlled successful landing of Vikram rover during the special 20-minute screening. The screening was followed by a question-answer session.

IUCAA will observe an open day on Saturday too.

No 'Open Day' at IISER, NCL

Most of the scientific institutions and research labs in the city had thrown open their gates, allowing visitors, school and college students into their labs and workspaces. But 100 students who visited Indian Institute of Science, Education and Research (IISER), Pune were denied entry into the institute.

While it is mandatory for government-run scientific institutions to observe an open day on National Science Day, IISER security personnel reportedly shut the gates on the visitors. The IISER administration clarified that the incident had occurred due to miscommunication.

Similarly, CSIR-National Chemical Laboratory (NCL) observed a Science Day that was meant for 'select invitees' only. Despite a lecture presented by Mission Shakti Project Director U Raja Babu from Hyderabad-based Defence and Research Development Organisation, only a select audience was able to attend it. During his public address on 'Technological Challenges: Missile and Space Missions', U Raja Babu shared that wars of current times were fought and were remotely controlled from multiple locations. He said, "Network centric warfare, information and cyber warfare will be predominant in the years to come."

Indian Express, Pune Feb.29, 2020, Newsline P.1

On Saturday, Reva
pursues his passi
in theatres and fi
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IUCAA IN NEWS

लोकसत्ता | पुणे दिनांक

विद्यापीठ-आयुका संशोधनासाठी एकत्र

संयुक्त अभ्यासक्रमांचीही निर्मिती करण्याची कल्पना

प्रतिनिधी, पुणे

सावित्रीबाई फुले पुणे विद्यापीठात गुणवान विद्यार्थी आहेत. त्यांच्यासाठी सध्याच्या आव्हानांवर आधारित अभ्यासक्रम विकसित करण्याची गरज आहे. त्यासाठी हा सामंजस्य करार मलत्वाचा आहे. विज्ञानाच्या बदलत्या स्थितीमध्ये अशाप्रकारे संयुक्तपणे काम करणे आवश्यक आहे.

– डॉ. नितीन करमळकर

भौतिकशास्त्र, खगोलशास्त्र, खगोलभौतिकी, अवकाश विज्ञान, वातावरण विज्ञान, उपकरणशास्त्र, तंत्रज्ञान अशा विविध विषयांत संशोधन करण्यासाठी सावित्रीबाई फुले पुणे विद्यापीठ आणि आंतरविद्यापी

संशोधनासाठी आयुका

विविध प्रकल्पांवर संयुक्तपणे काम करणार :

प्रभात वृत्तसेवा



संशोधनाबरोबरच विकास व शैक्षणिक कार्यक्रम राबविले जाणार किलोमीटर अरे (एस.के.ए.), आदित्य- एल १ अशा विविध

आयुकातर्फे विज्ञानविषयक व्याख्यान मालिकेचे आयोजन

लोकसत्ता प्रतिनिधी

पुणे: आंतरविद्यापीठीय खगोल आणि खगोलभौतिकी केंद्रातर्फे (आयुका) विज्ञानविषयक व्याख्यान मालिका आयोजित करण्यात आली आहे. सूर्य, अवकाश हवामान अशा विषयांवरील व्याख्यानांचा यात समावेश असून, आयुका आणि आयसरमध्ये ही व्याख्याने होत आहेत.

वॉज डिसकव्हर्ड' या विष
बंगळुरूच्या इंडियन इन्स्टिट्यूट
सायन्समधील प्रा. अर्णब राय
यांचे व्याख्यान झाले.
मुंबईच्या सेंटर फॉर एक्सल
बेसिक सायन्समधील प्रा. ए
चित्रे यांचे 'हाऊ वेल डू वुई
सन' या विषयावर मंगळ
फेब्रुवारी) सायंकाळी
वाजता आयसरच्या बाल

प्रारंभीच्या ब्र

भारत करणार जगाचे नेतृत्व; शास्त्र

पुणे, ता. २८ : आज अस्तित्वात असलेल्या ब्रह्मांडाबद्दल आपल्याकडे पुरेशी माहिती

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२ पुणे, शुक्रवार, दि. २२ मार्च २०१९

डॉ. गोविंद स्वरूप यांचे नव्वदीनिमित्त अभीष्टचिंतन : भारतीय रेडिओ खगोलशास्त्राचे जनक

आयुकामध्ये भरला ज्येष्ठ शास्त्रज्ञांचा मेळा

लोकमत न्यूज नेटवर्क

पुणे : भारतीय रेडिओ खगोलशास्त्राचे जनक डॉ. गोविंद स्वरूप यांच्या स्मरणी आयुकामध्ये भरला होता. डॉ. स्वरूप यांच्या मेहनतीमुळे भारतीय खगोल शास्त्राच्या झालेल्या विकासावर यावेळी प्रकाश टाकण्यात आला.

डॉ. गोविंद स्वरूप यांनी खगोलशास्त्रज्ञांची एक पिढी घडविली. त्यांचे अनेक विद्यार्थी आज जगभरात शास्त्रज्ञ म्हणून कार्यरत आहेत. गुरुवारी आयोजित कार्यक्रमास ज्येष्ठ खगोलशास्त्रज्ञ डॉ. जयंत नारळीकर, वैज्ञानिक सल्लागार प्रा. के. विजय राघवन, ज्येष्ठ शास्त्रज्ञ डॉ. अनिल काकोडकर, डॉ. राहुलण गाडेलकर, दक्षिण आफ्रिकेतील स्क्वेअर किलोमीटर प्रकल्पाचे प्रमुख प्रा. शपर्ड, डॉ. पद्मनाभन, शास्त्रीयाई पुणे पुणे विद्यापीठाचे कुलगुरु डॉ. नितीन करमळकर उपस्थित होते.

सायंकाळी सहभागच्या गुणगान डॉ. गोविंद स्वरूप व त्यांची पत्नी विजया स्वरूप यांचे अनुभवांवर चर्चासत्रात सादरीकरण झाले. एका नाटकातून डॉ. गोविंद स्वरूप यांच्या देदीप्यमान प्रवासाला यावेळी उजाळा दिला. डॉ. स्वरूप



भारतीय रेडिओ खगोलशास्त्राचे जनक डॉ. गोविंद स्वरूप यांचे अभीष्टचिंतन करताना (डावीकडून) ज्येष्ठ शास्त्रज्ञ डॉ. एच. एम. दिवे, डॉ. अनिल काकोडकर, डॉ. राहुलण गाडेलकर, प्रा. के. विजय राघवन आणि डिव्हा पुष्पगुच्छ भेट देताना डॉ. नितीन करमळकर.

मुळचे जात प्रदेशमधील, अलाहाबाद येथून १९५५मध्ये त्यांनी खिलिकर विषयात एमएससी केले. त्यानंतर त्यांनी ऑक्टेनियातील सिड्नी येथे रेडिओ दुर्बीण मूर्धन्यजबोधील भारतातील पहिली आधुनिक खगोलशास्त्र विषयक अभ्यासाला चालना दिली.

बैलगाडीच्या युगात रेडिओ दुर्बिणीची उभारणी

- डॉ. गोविंद स्वरूप यांनी पुणेकरांना सर्वात आधी गाठले. बैलगाडीच्या युगात सर्वात मोठ्या रेडिओ दुर्बिणीची स्थापनी करणे मोठे आव्हानात्मक होते. परंतु त्या वेळी आमच्या तरुण टीमने ते यशस्वीपणे पार पाडल्याची भावना डॉ. स्वरूप यांनी या वेळी व्यक्त केली.

अडथळ्यांवर केली मात

- रेडिओ दुर्बिणीची उभारणी करण्यामध्ये खूप अडचणी होती. ती अडचणींवर डॉ. गोविंद स्वरूप यांनी मात केली.
- सांग चेंज शास्त्रज्ञांच्या पहिले गुणेश देण्याताठी आली असल्याचे मुख्य पैजनिक सल्लागार प्रा. के. विजय राघवन यांनी सांगितले.

अद्ययावत जीएमआरटीचे उद्घाटन

जोडव येथील अद्ययावत जीएमआरटीचे या वेळी डॉ. गोविंद स्वरूप यांच्या हस्ते उद्घाटन करण्यात आले. आयुकामध्ये महाराष्ट्र राज्य शासनाकडून खोदण्यात आलेल्या गोविंद स्वरूप यांनी एक उत्कृष्ट खगोलतज्ज्ञ, मेंटर म्हणून काम केले. रेडिओ खगोलशास्त्रात त्यांचे योगदान महत्त्वपूर्ण राहिले आहे.

लोकसत्ता पु

पुण्याच्या वि

सिंहगड स्प्रिंगडेल स्कूलच्या

प्रतिनिधी, पुणे

प्रभात पुणे, शनिवार, दि. ५ ऑक्टोबर २०१९ ॥ ५

-विद्यापीठामध्ये करार

विकास व शैक्षणिक कार्यक्रम राबविले जाणार

विज्ञान व तंत्रज्ञान या विषयांमध्ये अभ्यास-संशोधन करण्याच्या दृष्टीने विद्यार्थ्यांच्या रूपाने मोठ्या संख्येने प्रशिक्षित मनुष्यबळ उपलब्ध आहे. ही या संस्थांची बलस्थाने संयुक्त संशोधनासाठी उपयुक्त ठरणारी आहेत. याकरारांतर्गत विद्यापीठातील भौतिकशास्त्र, वातावरण व अवकाश विज्ञान, तंत्रज्ञान, उपकरण विज्ञान हे विभाग 'आयुका'सोबत संयुक्तपणे

विद्यापीठात अनेक हुशार व प्रज्ञावान विद्यार्थी आहेत. त्यांच्यासाठी सध्याच्या काळातील आव्हानांवर आधारित अभ्यासक्रम विकसित करणे आवश्यक आहे. त्या दृष्टीने या सामंजस्य कराराचा उपयोग होईल. सध्याच्या विज्ञानाच्या दृष्टीने बदलत्या परिस्थितीत अशाप्रकारे संयुक्तपणे काम करण्याची गरज

विद्यापीठ आणि आयुका यांच्यात गेल्या तीन दशकांमध्ये शैक्षणिक विषयांवर सहकार्य झालेले आहे. आता या सामंजस्य कराराच्या निमित्ताने संशोधनाच्या क्षेत्रात संयुक्तपणे काम करण्यास सुरुवात केली जाणार आहे. भारत हा देश-विदेशातील महत्त्वाच्या संशोधन प्रकल्पांमध्ये सहभागी आहे. या

'आयुका'मध्ये विज्ञानप्रेमींची गर्दी

प्रभात वृत्तसेवा

पुणे, दि. २८ - राष्ट्रीय विज्ञान दिनानिमित्ताने सावित्रीबाई फुले पुणे विद्यापीठात विविध विज्ञान विभागांतर्फे विज्ञान प्रदर्शन व कार्यक्रमाचे आयोजन करण्यात आले होते. त्याचप्रमाणे 'आयुका'मध्ये विज्ञानप्रेमींची गर्दी होती. या निमित्ताने

राष्ट्रीय विज्ञान दिनानिमित्ताने विज्ञान प्रदर्शनासह विविध कार्यक्रम

भावसार स्मिता यांनी प्रास्ताविक केले. पाटील यांनी आभार मानले. दरम्यान, नऱ्हे येथील पॅराडाईज इंग्लिश मीडियम स्कूलतर्फे संस्थेच्या प्रांगणात विज्ञान प्रदर्शनाचे आयोजन करण्यात आले होते. संस्थेच्या खजिनदार सुरेखा जाधवर यांच्या हस्ते प्रदर्शनाचे उद्घाटन झाले. यावेळी शाळेचे मुख्याध्यापक व शिक्षक, पालक उपस्थित होते. प्रदर्शनात १०० पेक्षा अधिक प्रकल्पांचा समावेश होता. इयत्ता दुसरी ते नववी पर्यंतच्या विद्यार्थ्यांनी प्रदर्शनात प्रकल्प सादर करीत उत्साहाने सहभाग घेतला. विद्यार्थ्यांमधील विज्ञानाबद्दलचे कुतूहल निर्माण व्हावे आणि त्यांच्यातील संशोधन वृत्तीस देखील चालना मिळावा, याकरीता हे प्रदर्शन दरवर्षी आयोजित केले जाते. विद्यार्थ्यांच्या कल्पनाशक्तीला व्यासपीठ देत त्यांच्यातील वैज्ञानिक दृष्टीकोन जोपासण्याचा प्रयत्न यामाध्यमातून केला जातो. विद्यार्थीदशेतच मुलांना विज्ञानाची आवड निर्माण व्हावी, याकरीता असे उपक्रम वारंवार राबविण्यात येत असल्याचे त्यांनी सांगितले.

पुणे फेब्रुवारी २९, २०२० गुड मॉर्निंग, ४

पुणे शहर पुणे, शनिवार, २९ फेब्रुवारी २०२० II

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ह्मांडाचे उलगडणार गूढ

ज्ञ प्रा. तरुण सौरदीप यांची माहिती

पीठीय खगोलशास्त्र लभौतिकी केंद्रात विज्ञान दिनानिमित्त लेल्या 'ब्रह्मांडाच्या



विस्तारत जाणारे ब्रह्मांड, प्राचीन गुरुत्वीय लहरी याबद्दल आपण

देशाला मूलभूत विज्ञानात योगदान देण्याची सुवर्णसंधी 'सीएमबी-भारत' मोहिमेद्वारे निर्माण झाली आहे.

अशी आहे मोहीम



संशोधनासंबंधी विविध प्रकल्पांवर संयुक्तपणे काम करण्यासाठी विद्यापीठ आणि आयुका यांच्यात सामंजस्य करार करण्यात आला. यावेळी कुलगुरू डॉ. नितीन करमळकर आणि आयुकाचे संचालक डॉ. सोमक रेचौधरी यांच्यासह अन्य मान्यवर उपस्थित होते.

गातील पहिली मोहीम क्र-२' बिंदूवर उपग्रह

ये होणार फिजिक्सच्या

ठणार

संशोधन प्रकल्पासाठी विद्यापीठ-आयुका करार

पुणे : प्रतिनिधी

संशोधनासंबंधी विविध प्रकल्पांवर संयुक्तपणे काम करण्यासाठी गाविवीवार पुणे पुणे विद्यापीठ आणि इंटर युनिव्हर्सिटी सेंटर फॉर अस्ट्रॉनॉमी अँड ॲस्ट्रोफिजिक्स (आयुका) या दोन महत्त्वाच्या संस्थांमध्ये सुक्रवारी सामंजस्य करार करण्यात आला. त्याअंतर्गत भौतिकशास्त्र, खगोलशास्त्र, खगोलभौतिकी, अवकाश विज्ञान, वातावरण विज्ञान, उपकरणशास्त्र, तंत्रज्ञान आणि इतर महत्त्वाच्या विषयांवर संशोधनसहकार्य निर्माण व शैक्षणिक कार्यक्रम राबविले जाणार आहेत.

आयुकाचे संचालक डॉ.सोमक रेचौधरी, पीटर वॉटसन्कोप (टीएमटी), लेसर इंटरफेरोमेट्रिक ग्रॅव्हिटेशनल वेव्ह ऑब्जर्वेटरी (लिगो), स्क्वेअर किलोमीटर ॲरे (एस.के.ए.), आदित्य- एल १ आणि विविध महत्त्वाच्या प्रकल्पांवर काम सुरू आहे. त्याच बेसी सामंजस्य करार करण्यात आला. त्यामुळे विद्यापीठाकडे विज्ञान व तंत्रज्ञान या विषयांमध्ये अभ्यास-संशोधन

विद्यापीठात अनेक हुशार व प्रज्ञावान विद्यार्थी आहेत. त्यांच्यासाठी सध्याच्या काळातील आव्हानांवर आधारित अभ्यासक्रम विकसित करणे आवश्यक आहे. त्या दृष्टीने या सामंजस्य कराराचा उपयोग होईल.

- डॉ. नितीन करमळकर, कुलगुरू, सावित्रीबाई फुले पुणे विद्यापीठ

विद्यापीठ आणि आयुका यांच्यात गेल्या तीन दशकांपासून शैक्षणिक विषयांवर सहकार्य झालेले आहे. आता या सामंजस्य कराराच्या निमित्ताने संशोधनाच्या क्षेत्रात संयुक्तपणे काम करण्यास सुरुवात केली जाणार आहे.

- डॉ. सोमक रेचौधरी, संचालक, आयुका

करारांतर्गत विद्यापीठातील भौतिकशास्त्र, वातावरण व

तला. यावेळी प्राचार्या डी, पर्यवेक्षिका भुजबळ नी मार्गदर्शन केले.

गे दिनांक

द्यार्थ्याकडून ग्रहाचे नामकरण

विद्यासागर दौडची कामगिरी

मिकल सोसायटी ऑफ इंडियाच्या माध्यमातून भारतीय सूचवण्यात आलेली दोन्ही नावे आंतरराष्ट्रीय खगोल ारली आहेत. या स्पर्धेतील विजेत्यांचा आणि अंतिम ांचा यथोचित गौरव करण्यात येणार आहे.

ी. अनुपमा, अध्यक्षा, वेरॅट्रोनॉमिकल सोसायटी ऑफ इंडिया



समितीकडून या नावांची छाननी करून १० नावे अंतिम फेरीसाठी निवडण्यात आली. अंतिम फेरीत खुले मतदान घेण्यात आले. जवळपास ५ हजार ५८७ नागरिकांनी केलेल्या मतदानानंतर दोन नावे निश्चित करण्यात आली.

त्यात अनन्यो भट्टाचार्यने एचडीं८६०८१ या ताऱ्याला 'बिभा' हे नाव सुचवले आहे. 'प्रखर किरण' असा या नावाचा अर्थ आहे. भारतीय शास्त्रज्ञ डॉ. बिभा चौधरी यांच्या स्मरणार्थ हे नाव सुचवण्यात आले होते. तर १३ वर्षांच्या विद्यासागर दौडने एचडीं८६०८१ या ग्रहाला 'संतमस' हे नाव सुचवले. त्याचा अर्थ 'ढगांनी आच्छादित' असा आहे.

गोल महासंघाच्या इंडिया' स्पर्धा जुलैमध्ये जाहीर ाब्दी वर्षनिमित्त करण्यात आली होती. ाकरण करण्याची विद्यार्थ्यांना खगोलशास्त्र, ातळीवर घेण्यात विज्ञानाची गोडी लागावी हा या एक भाग म्हणून स्पर्धेचा उद्देश होता. या स्पर्धेत ीय भाषांतील नाव देशभरातून १ हजार ७१७ मेम एक्झोवर्ल्ड्स विद्यार्थ्यांनी सहभाग घेतला. तज्ज्ञ

IUCAA IN NEWS

पुढारी, पुणे फेब्रुवारी, २९, २०२० पृ. ३

वैज्ञानिक प्रगतीसाठी दर्जेदार संशोधनाची गरज

ज्येष्ठ शास्त्रज्ञ डॉ. जयंत नारळीकर यांचे मत



लोकमत

जयंत नारळीकर : तापमानावरून ठरतो ताऱ्याचा रंग

मंत्रासारखे पाठ करून विज्ञान येत नाही

लोकमत न्यूज नेटवर्क

पुणे : "शालेय विद्यार्थ्यांना विज्ञान हे मंत्रासारखे पाठ करून शिकविले जाते. त्यामुळे विद्यार्थी मार्क मिळविण्यापुरते विज्ञान शिकतात. मोठे झाल्यावर त्यांचे कुतूहल कमी होत जाते. त्यामुळे विज्ञान वाढत का नाही, याचे कारण आपण आपल्यातच शोधायला हवे," असे मत ज्येष्ठ शास्त्रज्ञ डॉ. जयंत नारळीकर यांनी व्यक्त केले.

सावित्रीबाई फुले पुणे विद्यापीठातील आयुकामध्ये विज्ञान दिनानिमित्त शुक्रवारी (दि. २८) शास्त्रज्ञांशी संवादाच्या कार्यक्रमाचे आयोजन करण्यात आले होते, त्या वेळी ते बोलत होते. नारळीकर आणि आयुकाचे शास्त्रज्ञ सोमक रायचौधरी यांनी उपस्थित विद्यार्थ्यांच्या प्रश्नांना उत्तरे दिली.

अवकाशात तारे असताना अवकाश काळे का दिसते, या प्रश्नाचे



विज्ञान दिनानिमित्त आयुकामध्ये आयोजित कार्यक्रमात बोलताना डॉ. जयंत नारळीकर. समवेत शास्त्रज्ञ सोमक रायचौधरी.

अवकाश प्रकाशमान करण्यासाठी पुरेसे नाहीत. त्यामुळे ते तारे आपल्याला दिव्यांसारखे दिसतात." ताऱ्यांच्या रंगाबाबत ते म्हणाले, की भौतिकशास्त्रानुसार ताऱ्यातून किरणोत्सर्ग होत त्यांच्या तापमानावरून त्या ताऱ्याचा रंग ठरतो. लाल रंग सर्वांत जास्त तप्त असल्याचे आपल्याला वाटते, परंतु विज्ञानानुसार असतो. सूर्यासारखे अनेक त आकाशगंगेत आहेत. एका ठ्याना सूर्यात अनेक बदल होतील. त्य तापमान बदलेल, तसेच त्या आकारही बदलण्याची शक्यता आ प्राथीण भागात विज्ञान जास्त कसे पोहोचायला हवे, प्रश्नाच्या उत्तरात नारळीकर म्ह "विज्ञान सर्वांपर्यंत पोहोचायला केवळ शहरांपुरते ते मर्यादित

विद्यार्थ्यांना विज्ञानात रुची निर्माण करायची असेल तर विविध कथानके वापरली पाहिजेत. यातून विज्ञानाची गोडी निर्माण करता येईल, असे डॉ. नारळीकर म्हणाले. विज्ञानकाळातसुद्धा भोंदू बाबांचे प्रस्थ दिसते, यावर ते म्हणाले, "समाजाचे प्रबोधन आवश्यक आहे. नाटक किंवा इतर माध्यमांमधून विज्ञान, सत्य लोकांसमोर मांडले पाहिजे.

लोकसत्ता पु

विद्यापी संशोधना

संयुक्त अभ्यासक्रमांच

लोकमत

विद्यापीठ व आयुकाचे एकत्रित संशोधन

लोकमत न्यूज नेटवर्क

सावित्रीबाई फुले पुणे विद्यापीठ दशकांमध्ये शैक्षणिक विषयांव सामंजस्य कराराच्यानिमित्ताने संशोधन सुरुवात केली जाणार आहे. संशोधन सहकार्य करण्याची गरज आहे. या दि - डॉ.

संबंधी विविध काम करण्यासाठी णे विद्यापीठ व र फॉर ॲस्ट्रॉनॉमी (आयुका)मध्ये करार केला. या च्या विषयांवर विकास व ाधणार आहेत. ध्या थर्टी मीटर मटी), लेसर

प्रकल्पांवर कार्यरत आहे. त्या विद्यापीठाकडे विज्ञान व तंत्र विषयांमध्ये अभ्यास-र करण्याच्या दृष्टीने विद्यार्थ्यांच्य मोठ्या संख्येने प्रशिक्षित म

पुणेयाची ओळख

» पान १ वरून

याबाबत

सकाळ

मतदान हे राष्ट्रीय कर्तव्य : डॉ. नारळीकर



डॉ. नारळीकर

पुणे, ता. २० : "मतदान करणे ही सर्वांची महत्त्वाची जबाबदारी आहे. ज्या भावनेने आपण राष्ट्रीय उत्सव साजरा करतो, त्याच आवश्यक आहे," असे प्रतिपादन ज्येष्ठ शास्त्रज्ञ डॉ. जयंत नारळीकर यांनी केले.

जिल्हा प्रशासनाच्या 'स्वीप' कार्यक्रमांतर्गत 'स्वीप' कार्यक्रम व्यवस्थापन समिती आणि भोई प्रतिष्ठान यांच्या वतीने मतदान जागृती कार्यक्रमातील बैठकीत ते बोलत होते. बजाविण्याची गरज आहे. प्रलोभनाला बळी न पडता सदसद्विवेकबुद्धीने मतदान करा."

त्यांच्या पत्नी मंगला नारळीकर म्हणाल्या, "आम्ही जगात कोठेही असलो, तरी न चुकता मतदानासाठी भारतात येतो."

मतदान जनजागृती 'स्वीप'

आव्हाने पेलण्य ज्ञान समूहासाठ

प्रतिनिधी, पुणे

शापुढील आव्हानांवर विज्ञान णि तंत्रज्ञानाच्या बळावरच मात रता येईल. त्या दृष्टीनेच शिक्षण, संशोधन संस्था आणि उद्योगांना एकत्र आणून पुण्यात 'विज्ञान तंत्रज्ञान ज्ञान समूह' (सायन्स टेक्नॉलॉजी नॉलेज क्लस्टर) उभारण्यात येणार आहे. या तिन्ही क्षेत्रात आघाडीवर असण्याबरोबरच आव्हाने पेलण्याची आणि नेतृत्व करण्याची क्षमता असल्यानेच पुण्याची या समूहासाठी निवड करण्यात आली असून, २६ सप्टेंबरला दिल्लीत होणाऱ्या बैठकीत समूहासंदर्भातील पुढील दिशा ठरवली जाणार आहे, असे केंद्र शासनाचे प्रधान वैज्ञानिक सल्लागार के. विजयराघवन यांनी गुरुवारी स्पष्ट केले.

समूहासंदर्भातील उच्चस्तरीय बैठकीसाठी आणि पुढील आराखडा ठरवण्यासाठी

प्रधान वैज्ञानिक स

आयुकामध्ये आले होते. त्यां त्यांनी पत्रकारांशी संवाद सा आयुकाचे संचालक स रायचौधुरी या वेळी उपस्थित 'विज्ञान तंत्रज्ञान ज्ञान समूह' शासनाच्या महत्त्वाकांक्षी प्रकल्प एक आहे. सुरुवातीला प्रकल्पासाठी सहा शहरांचा होता. मात्र, त्यातून पुण्यासह आणि दिल्ली यांची निवड आली आहे.

गेली काही वर्षे शास्त्र आणि तंत्रज्ञान क्षेत्रावर विशे आहे. त्याचा समाज अर्थव्यवस्थेवरही स परिणाम होत आहे.

मात्र आता देशासमो बदलासह अनेक प्रकार आहेत. या आव्हानांना बळावरच सामोरे जाता आणि तंत्रज्ञानाच्या क्षेत्रा

प्रभात पुणे, शनिवार, दि. ५ ऑक्टोबर २०१९ ॥ ५

संशोधनासाठी आयुका-विद्यापीठामध्ये करार

विविध प्रकल्पांवर संयुक्तपणे काम करणार : विकास व शैक्षणिक कार्यक्रम राबविले जाणार

प्रभात वृत्तसेवा

पुणे, दि. ४ - संशोधनाच्या विविध प्रकल्पांवर संयुक्तपणे काम करण्यासाठी सावित्रीबाई फुले पुणे विद्यापीठ आणि इंटर युनिव्हर्सिटी सेंटर फॉर अस्ट्रॉनॉमी ॲंड अस्ट्रोफिजिक्स (आयुका) या दोन महत्त्वाच्या संस्थांमध्ये आज सामंजस्य करार करण्यात आला. त्याअंतर्गत भौतिकशास्त्र, खगोलशास्त्र, खगोलभौतिकी, अवकाश विज्ञान, वातावरण विज्ञान, उपकरणशास्त्र, तंत्रज्ञान आणि इतर महत्त्वाच्या विषयांवर



संशोधनाबरोबरच विकास व शैक्षणिक कार्यक्रम राबविले जाणार आहे.

'आयुका'तर्फे सध्या थर्टी मीटर टेलिस्कोप (टीएमटी), लेसर इंटरफेरोमेट्रिक ग्रॅव्हिटेशनल वेव्ह ऑब्झर्वेटरी (लिगो), स्केअर किलोमीटर ॲरे (एस.के.ए.), आदित्य- एल १ अशा विविध महत्त्वाच्या आणि प्रकल्पांवर काम सुरू आहे. तर पुणे विद्यापीठ हे राष्ट्रीय आणि आंतरराष्ट्रीय पातळीवरील महत्त्वाच्या प्रकल्पांवर कार्यरत आहे. विद्यापीठाकडे विज्ञान व तंत्रज्ञान या विषयांमध्ये अभ्यास-संशोधन करण्याच्या दृष्टीने विद्यार्थ्यांच्या रूपाने मोठ्या संख्येने प्रशिक्षित मनुष्यबळ उपलब्ध आहे. ही या संस्थांची बलस्थाने संयुक्त संशोधनासाठी उपयुक्त ठरणारी आहेत. याकारांतर्गत विद्यापीठातील भौतिकशास्त्र, वातावरण व अवकाश विज्ञान, तंत्रज्ञान, उपकरण विज्ञान हे विभाग 'आयुका'सोबत संयुक्तपणे काम करतील. त्यात प्राध्यापक, संशोधक, पदव्युत्तर विद्यार्थी तसेच, पीएचडीनंतर संशोधन करणारे विद्यार्थी सहभागी असतील. त्यासाठी विद्यापीठ व आयुकाच्या

"विद्यापीठात अनेक हुशार व प्रज्ञावान विद्यार्थी आहेत. त्यांच्यासाठी सध्याच्या काळातील आव्हानांवर आधारित अभ्यासक्रम विकसित करणे आवश्यक आहे. त्या दृष्टीने या सामंजस्य कराराचा उपयोग होईल. सध्याच्या विज्ञानाच्या दृष्टीने बदलत्या परिस्थितीत अशाप्रकारे संयुक्तपणे काम करण्याची गरज आहे.

डॉ. नितीन करमळकर
कुलगुरु, सावित्रीबाई पुले पुणे विद्यापीठ

"विद्यापीठ आणि आयुका यांच्यात गेल्या तीन दशकांमध्ये शैक्षणिक विषयांवर सहकार्य झालेले आहे. आता या सामंजस्य कराराच्या निमित्ताने संशोधनाच्या क्षेत्रात संयुक्तपणे काम करण्यास सुरुवात केली जाणार आहे. भारत हा देश-विदेशातील महत्त्वाच्या संशोधन प्रकल्पांमध्ये सहभागी आहे. या परिस्थितीत संशोधन संस्थांनी विद्यापीठासारख्या संस्थांशी सहकार्य करण्याची गरज आहे.

डॉ. सोमक चौधरी
संचालक, आयुका

आवारात जागा उपलब्ध करून दिली जाईल.

प्रभात Sat, 05 October 2019
epaper.eprabhat.net/c/44370018

पुण्याची ओळख आता 'नॉलेज क्लस्टर'

पुणे, ता. १९ : पुणे

णे दिनांक

ड-आयुका
ासाठी एकत्र
ीही निर्मिती करण्याची कल्पना

सावित्रीबाई फुले पुणे विद्यापीठात गुणवान विद्यार्थी आहेत. त्यांच्यासाठी सध्याच्या आव्हानांवर आधारित अभ्यासक्रम रसित करण्याची गरज आहे. त्यासाठी हा सामंजस्य करार महत्त्वाचा विज्ञानाच्या बदलत्या स्थितीमध्ये अशाप्रकारे संयुक्तपणे काम णे आवश्यक आहे.

- डॉ. विनीन करमळकर, कुलगुरू, सावित्रीबाई फुले पुणे विद्यापीठ

सावित्रीबाई फुले पुणे विद्यापीठ आणि आयुकामध्ये गेल्या तीन दशकांत शैक्षणिक विषयांवर सहकार्य झाले आहे. या सामंजस्य करारामुळे योधनासाठी संयुक्त रीत्या काम करता येईल. जगभरातील महत्त्वाच्या संशोधनाचा सहभाग आहे. त्यामुळे संशोधन

WWW.LOKSATTA.COM
शनिवार, २९ फेब्रुवारी २०२०

पुणे दिनांक | लोकसत्ता

विज्ञान प्रदर्शने, व्याख्यानांद्वारे शाळांमध्ये विज्ञान दिन साजरा

लोकसत्ता प्रतिनिधी

पुणे : विद्यार्थ्यांनी तयार केलेले विषयपूर्ण प्रकल्प... विद्यार्थ्यांना प्रदान समजावण्यासाठी तज्ज्ञांची शाळेने... वैज्ञानिक उपकरणांची विविध आणि ओळख... संस्था भेटी या विविध उपक्रमांद्वारे शहरातील शाळांमध्ये 'विज्ञान दिन' साजरा पात आला.

वाजीनगर येथील पुणे पोलीस क स्कूलमध्ये विज्ञान-कला- प्रदर्शनाचे उद्घाटन पोलिसचे संस्थापक अध्यक्ष ब. मुजुमदार यांच्या हस्ते . गार्गी मिश्र, मुख्याध्यापिका रे आणि पूर्व प्राथमिक या मुख्याध्यापिका गीते ांची या चौथी उपस्थिता रोबो गणदिप चित्रकार्यच्या ी विद्यार्थ्यांनी काढलेली शिक्षनल मॅजिक' या मांडण्यात आली. तर, ान क्रीडा प्रदर्शनात विज्ञान आणि खेळांवर ली प्रारूपे मांडण्यात

पॅराडाईज इंग्लिश र्फे आयोजित विज्ञान ांच्या पार्किंगची ासाठी विज्ञान, साधने आणि तोटे.



नहाराष्ट्रीय मंडळाच्या टिळक रस्ता येथील इंग्रजी माध्यमाच्या शाळेतील विद्यार्थ्यांनी तयार केलेले वैज्ञानिक प्रकल्प प्रदर्शनात मांडण्यात आले होते.



राष्ट्रीय विज्ञान दिनानिमित्त आंतरविद्यापीठीय खगोल आणि खगोलभौतिकी केंद्रातर्फे (आयुका) व्याख्याने, वैज्ञानिक प्रकल्पांच्या प्रतिकृतींची मांडणी असे विविध उपक्रम आयोजित करण्यात आले आहेत. त्यात शुक्रवारी विद्यार्थ्यांनी जीएसएलव्ही उपग्रहाची प्रतिकृती पाहिली, तसेच ज्येष्ठ खगोलशास्त्रज्ञ डॉ. जयंत नारळीकर आणि आयुकाचे संचालक डॉ. सोमक रायचौधुरी यांनी विद्यार्थ्यांशी संवाद साधून त्यांच्या प्रश्नांना उत्तरे दिली.

संगणकाच्या सुयोग्य वापर, सौर ऊर्जेवरील आत्याधुनिक उपकरणे, इलेक्ट्रॉनिक्स उपकरणे,लॅपटॉप, मायक्रोवेव्ह प्रदर्शनाला भेट देऊन विद्यार्थ्यांशी संवाद साधला.

पुण्यातील विद्यार्थ्यांकडून बाह्यग्रहाचे बारसे

ताऱ्याला 'बिभा', तर ग्रहाला 'संतमस' नावाने ओळख

म. टा. प्रतिनिधी, पुणे



विद्यासागर दौड

पृथ्वीपासून ३४० प्रकाशवर्षे दूर सणारा एक तारा आणि त्याभोवती रणाऱ्या एका ग्रहाचे इंटरनॅशनल स्ट्रोनॉमिकल युनियनतर्फे आयएयू) भारतीय नामकरण रण्यात आले आहे. सिंह आणि सुकी तारकासमूहाच्या दरम्यान सणाऱ्या षडंश (सेक्स्टंस) या हानशा तारकासमूहातील एका ाला बिभा (विभा - प्रखर र्यकिरण), तर त्याभोवती फिरणाऱ्या ाला संतमस (ढगाळ) या भारतीय ांनी ओळखले जाईल. बिभा हे व सुरतमधील अनन्यो भट्टाचार्य या स वर्षीय विद्यार्थ्याने, तर संतमस नाव पुण्यातील विद्यासागर दौड या

बाह्य सूर्यमालेचे भारतीय नामकरण

ताऱ्यासाठी बिभा हे नाव सुरत येथील अनन्यो भट्टाचार्य या वीस वर्षीय विद्यार्थ्याने सुचवले आहे. विभा संस्कृत या शब्दाचा बिभा हा बंगाली उच्चार असून, त्याचा अर्थ प्रखर किरण असा होतो. बिभा हा तारा आपल्या सूर्यापेक्षा वयस्कर, आकाराने थोडा मोठा आणि अधिक तापमान असणारा पिवळा तारा आहे. बिभा या नावातून ज्येष्ठ खगोलशास्त्रज्ञ डॉ. बिभा चौधरी यांचाही गौरव होतो. ग्रहाला देण्यात आलेले संतमस हे नाव पुण्यातील विद्यासागर दौड या सिंहगड स्प्रिंगडेल पब्लिक स्कूलमध्ये आठवीत शिकणाऱ्या विद्यार्थ्याने सुचवले आहे. संतमस या संस्कृत शब्दाचा अर्थ ढगांनी वेढलेला असा होतो. हा ग्रह आपल्या सूर्यमालेतील गुरुसारखाच वायुरूपी आणि प्रचंड वस्तुमानाचा आहे. मात्र, तो ग्रह बिभा या ताऱ्यापासून कमी अंतरावरून फिरत असल्यामुळे त्यावरील तापमान जास्त असण्याची शक्यता आहे.

दुसऱ्या ताऱ्यांच्या भोवती फिरणाऱ्या सुमारे चार हजार ग्रहांचा आतापर्यंत शोध लागला आहे. त्यांपैकी लहान दुर्बिणीद्वारे दिसू शकणाऱ्या ताऱ्यांचे आणि त्यांच्याभोवती फिरणाऱ्या ग्रहांचे नामकरण करण्याचा उपक्रम आयएयूने सुरु केला. त्यासाठी जगभरातील ११० देशांना त्यांच्या देशातून दिसू शकणाऱ्या प्रत्येकी एका ताऱ्यासह त्या ताऱ्याभोवती फिरणाऱ्या ग्रहमालेचे स्थानिक भाषेत नामकरण करण्याची संधी देण्यात आली.

भारतासाठी षडंश (सेक्स्टंट) या तारकासमूहातील 'एचडी ८६०८१' या क्रमांकाचा तारा आणि त्याभोवती फिरणारा एचडी ८६०८१ बी हा एक ग्रह नामकरणासाठी उपलब्ध होता. ॲस्ट्रोनॉमिकल सोसायटी ऑफ इंडियातर्फे जुलै २०१९ पासून तारा आणि ग्रहाच्या नावांसाठी देशभरातून प्रस्ताव मागवण्यात आले. अंतिम तारा आणि ग्रहासाठी सुचवण्यात आलेल्या १७१७ नावांमधून अंतिम पाच नावांची

आता 'नॉलेज क्लस्टर'

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शुक्रवार, २० सप्टेंबर २०१९ ५

संशोधन
जाणार
रस
ग्याची
ाईल.
भाणि

ाच्या क्षमतेमुळेच
ी पुण्याची निवड

ल्लागार के. विजयराघ

क्लस्टरमुळे रोजगार

विज्ञान तंत्रज्ञान ज्ञान समृद्धतेच्या पदांवर भरतीस्तव नवे रोजगार किती, कसे आणि कोणत्या स्व रोणार नाही, असे विजयराघव ास्सिलोना अशा शहरांमध्ये त्यांनी सांगितले.

बळ देण्यासाठी मोठ्या आर्थिक गुंतवणूकही करण्य आहे. समूहामध्ये दोन पद्ध होईल. पहिल्या पद्धतीम स्तरावरून देशापुढील जगापुढील समस्या सां सांगितले जाईल. दुसऱ्या शहरातील शैक्षणिक, आणि संशोधन संस्था समस्या, आव्हाने निर्दि एकमेकांच्या साधनसुवि करून त्यावर उपाय

सकाळ, पुणे फेब्रुवारी २९, २०२० पृ. II

जिज्ञासेला प्रोत्साहन देणारे शिक्षण हवे : नारळीकर

विज्ञानप्रेमींनी तुडुंब भरलेले सभागृह. अगदी परभणी, लातूर जिल्ह्यातून आलेल्या विद्यार्थ्यांशी ज्येष्ठ शास्त्रज्ञ डॉ. जयंत नारळीकर यांनी शुक्रवारी संवाद साधला. राष्ट्रीय विज्ञानदिनी आयोजित या कार्यक्रमात बोलताना त्यांनी देशात जिज्ञासेला प्रोत्साहन देणाऱ्या शिक्षण व्यवस्थेची गरज व्यक्त केली.

आंतरविद्यापीठीय खगोलशास्त्र आणि खगोलभौतिकी केंद्र (आयुका) येथे आयोजित कार्यक्रमात संचालक डॉ. शोमंक राय चौधरी आणि डॉ. नारळीकर यांनी विद्यार्थ्यांशी संवाद साधला. डॉ. सुहृद मोरे आणि डॉ. अनुप्रीता मोरे यांनी कार्यक्रमाचे सूत्रसंचालन केले. ग्रामीण भागातील वैज्ञानिक केंद्राबद्दल प्रश्न विचारताना डॉ. नारळीकर म्हणाले, "देशाच्या शैक्षणिक धोरणाबद्दल पुनर्विचार करायला हवा. केवळ घोकमपट्टीवर आधारित शिक्षण व्यवस्था नको. आपण जिज्ञासेला महत्त्व देणे गरजेचे आहे."



डॉ. नारळीकर

विज्ञानदिनी 'आयसर'चे दरवाजे बंद

राष्ट्रीय विज्ञानदिनी शहरातील सर्वच वैज्ञानिक संस्थांचे दरवाजे सामान्यांसाठी खुले होते; पण भारतीय विज्ञान शिक्षण आणि संशोधन संस्थेत (आयसर) विज्ञान दिनाचे कोणतेच आयोजन करण्यात आले नव्हते. दुपारी आयसरच्या भेटीसाठी गेलेल्या काही विद्यार्थ्यांना दरवाजातूनच परत पाठविण्यात आले. अधिकाऱ्यांना विचारले असता त्यांनी यासंबंधी कोणतीच माहिती दिली नाही.





PUBLIC LECTURES

May 22, 2019: **Puragra Guha Thakurta** (University of California, Santa Cruz), on *Galaxies, Dark Matter, and Life on Earth.*

October 22, 2019: **Gary Melnick** (Center for Astrophysics, Harvard - Smithsonian, USA), on *Interstellar Water: Past, Present, and Future.*

January 8, 2020: **Bhuvnesh Jain,** (University of Pennsylvania), on *Pursuing the Shadow of a Black Hole.*

February 3, 2020: **Arnab Rai Choudhuri** (Indian Institute of Science, Bengaluru), on *How the Saha Ionization Equation was Discovered.*

All the talks are available at our YouTube Channel
https://www.youtube.com/user/IUCAASciPOP/

SECOND SATURDAY LECTURES

July 13, 2019: **Jayant Narlikar** (IUCAA), on Why Study Astronomy?

November 16, 2019: **Pratik Dabhade** (IUCAA), on *Radio Signals from Space: Unveiling the Mysteries of the Universe,*

December 14, 2019: **Samir Dhurde** (IUCAA), and Geeta Mahashabde (Navnirmiti Learning Foundation, Pune), on *Observing Solar Eclipse on December 26, 2019.*

February 8, 2020: **Helen Mason** (University of Cambridge), on *From Sun to Earth* (in English).

February 8, 2020: **Samir Dhurde** (IUCAA), on *From Sun to Earth* (in Marathi).








EXIT

ACADEMIC CALENDAR



ANNUAL EVENTS AT IUCAA

2019

April 17 -20
National Conference on Recent Trends in the Study of Compact Objects: Theory and Observations

May 6 - 31
School Students' Summer Programme and Astronomy Camp

May 13 - June 14
Refresher Course in Astronomy and Astrophysics

May 13 - June 28
Vacation Students' Programme

2020

February 28
National Science Day

EVENTS AT IUCAA

2019

August 16 - 24
Indo - French Astronomy School (IFAS5) on Spectroscopy and Spectrographs

September 19
Pune Knowledge Cluster (PKC) Town Hall Meeting

October 22 - 25
International Conference on Infrared Astronomy and Astrophysical Dust

November 13 - 14
SALT Science Meeting

December 3 - 5
Indo-Chilean Astronomical Dialogue- II

December 4 - 6
Newton-Bhabha Open Data Indo-UK Workshop

December 16 - 24
IUCAA - NCRA Radio Astronomy Winter School

December 18 - 21
FINESSE Workshop and Hackathon: Hands-on Interferometer Modelling

December 29
Foundation Day

2020

February 3 - 7
5th Asia-Pacific Solar Physics Meeting

March 7 - 11
FINESSE Workshop and Hacakthon: Hands-on Interferometer Modelling

EVENTS OUTSIDE IUCAA

2019

April 27 - 28
Astronomy Congress - 2019
At: Calicut University, Kozhikode.

May 11 - June 1
Advanced B.Sc. (Physics) Summer programme
At: St. Xavier's College, Ahmedabad

May 24 - 28
Workshop on Data Analysis and Machine Learning
At: IISER, Tirupati

August 19 - 24
Workshop on Engineering Applications in Astronomy
At: Vishwakarma Institute of Technology, Pune

August 29 - 30
Introductory Workshop on Astronomy and Astrophysics
At: Union Christian College, Aluha.

September 11 - 13
North-East Meeting of Astronomers (NEMA-V)
At: Tezpur University.

September 17 - 19
Workshop on Astronomical Data Analysis
At: Jagannath Barooah College, Jorhat, Assam

October 11 - 13
Workshop on General Relativity and Cosmology
At: GLA University, Mathura

October 14 - 17
Workshop on Python use in Physics and Astronomy
At: Kashmir University, Srinagar

October 30 - 31
Introductory Workshop on Physical Perspectives of Astronomy
At: ICFAI University, Tripura

November 8 - 10
Workshop on Emergent Gravity Paradigm
At: CUSAT, Kochi

November 20 - 22
Workshop on Statistical Applications in Astronomy and Astrophysics
At: Assam University, Silchar

November 20 - 22
National Workshop on AstroSat Data Analysis
At: Goa University

November 21 - 22
Workshop on Exploring the Universe
At: D.D.U. Gorakhpur University, and LBSPG college, Gonda.

November 25 - 30
Short Term Course on Gravitation and Cosmology for College Teachers
At: Providence Women's College, Kozhikode.

November 26 - 27
Workshop on Concepts in Astrophysics
At: Marthoma College, Nilambur.

December 15 - 16
International Workshop on LIGO-India
At: SRTM University, Nanded

December 16 - 17
National Seminar on Applications of Statistics in Natural Sciences
At: St. Xavier's College, Kolkata

December 19 - 22
Indian Association of Physics Teachers Under-Graduates Camp in Physics and Astronomy
At: BITS-Pilani, Goa Campus

December 26 - 29
Workshop on Science of the Star in our Backyard: Introduction and Data Analyis
At: St. Mary College, Wayanad.

2020

January 4 - 11
IUCAA-CUTN School on Introductory General Relativity and Cosmology (ICSIGRC)
At: Central University of Tamil Nadu, Thiruvarur.

January 20 - 31
International Conference and School on the First Billion Years of the Universe using Next-Generation Telescopes
At: IIT, Indore

January 31 - February 1
Workshop on Astrophysics and Astronomy for Women in India
At: Diamond Harbour Women's University, Sarisha.

February 1 - 2
Seminar on X-ray Astronomy
At: St. Thomas College, Ranni

February 17 - 18
Frontiers of Physics-VIIII
At: Fergusson College, Pune

AWARDS AND RECOGNITIONS

Debarati Chatterjee

Open Badges (digital) Award, by Le Dȹme Science Centre in Caen, France for the following skills/achievements in science outreach:

- Dissemination of Scientific Culture (June 3, 2019)
- Contribution to the Community Pint of Science (September 3, 2019)
- Contribution to the Community Reflections (November 25, 2019)
- Contribution via Social Media (February 20, 2020)
- Expertise in Popularization of Research (March 26, 2020)

Avyarthana Ghosh

- **K. D. Abhyankar Best Thesis Presentation Award (2020)**, by the Astronomical Society of India, during the 38th Annual Meeting of the ASI at IISER-Tirupati.

Ajit K. Kembhavi (IUCAA), and Pushpa Khare (Former Visiting Associate of IUCAA, from the Department of Physics, Utkal University, Bhubaneswar)

- **Mahatma Jyotirao Phule Puraskar (2018)**, for their Marathi book: **Guruttviy Tarang-Vishwdardshnache Nave Sadhan (Gravitational Waves - A New Tool to Watch and Understand Universe)**, by the Maharashtra Rajya Sahitya ani Sanskruti Mandal, under the category of Science and Technology (including Computer and Internet). This award was been given by the Government of Maharashtra, under The Late Yashwantrao Chavan State Literature Award Scheme.

Jayant V. Narlikar

- **Justice Mahadeo Govind Ranade Memorial Award** (2019), on April 26, 2019.
- **Doctor of Science (Honoris Causa)**, from the University of Kerala, on August 22, 2019.
- **Brahmabhushan Puraskar**, by the Brahmin Seva Mandal, Mumbai, on December 14, 2019.
- **Distinguished Alumnus Award**, from the Banaras Hindu University, on January 17, 2020.
- **Sir Asutosh Mookerjee Memorial Medal** (2019), from the University of Calcutta, on January 28, 2020.
- **Sir Dr. M.S. Gosavi Excellence Award** (2020), from the Gokhale Education Society, Nashik, on February 19, 2020.

T. Padmanabhan

- **M. P. Birla Memorial Award** (2019).

Kandaswamy Subramanian

- Elected as a Fellow of the Indian National Science Academy.





RESEARCH GRANTS AND FELLOWSHIPS

Dipankar Bhattacharya

- ISRO Grant to set up the AstroSat Science Support Cell (ASSC).
- DST Indo – Italian Gant for the project: AstroSat: A New Window on General Relativity.

Debarati Chatterjee

- Alexander von Humboldt Renewed Research Stay Grant.

Subhadeep De

- Under the "Quantum Enabled Science and Technology (QuEST)" of the DST, grant for the project: Optical Clock Based Accurate Time Stamping in Quantum Communication.

Sanjeev Dhurandhar

- NASI Senior Scientist Platinum Jubilee Fellowship.

Neeraj Gupta

- CEFIPRA Grant for the project: Cosmological Evolution of Cold Gas from Quasar Absorption Lines.

Ajit Kembhavi

- NKN Grant for the project: Data Driven Initiative in Astronomy and Biology.
- NKN Grant for the project: Data Driven Initiatives in Astronomy and Biology- Joint Big Data Mining.
- DST Indo – US Science and Technology Forum (IUCCTF) Grant for the project: Pragadh; Indo – US Centre for Pan Astronomical Deep Learning.
- DAE Raja Ramanna Fellowship (Track – 1).
- Navajbhai Ratan Tata Trust Grant for the project: Gravitational Wave Data and Science Centre (GWDSC).

Ranjeev Misra

- UGC – UKERI Partnership Grant for the project: New Frontiers in Multi-wavelength Astronomy Correlated Variability of Accreting Black Holes and Neutron Stars from Optical to X-rays.
- Southampton University Grant for the project: Southampton – IUCAA Training for Astronomy Research and Education (SITARE).

Sanjit Mitra

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

T. Padmanabhan

- DST J. C. Bose Fellowship.

Isha Pahwa

- DST INSPIRE Fellowship.

Aseem Paranjape

- DST - SERB: Ramanujan Fellowship.

A. N. Ramaprakash

- Participation Grant in Thirty Metre Telescope Project.
- ISRO Grant for Design, Development and Supply of Solar Ultraviolet Imaging Telescope (SUIT) for Aditya - L1 Mission.
- Infosys Foundation Grant for Resurgent Caltech – IUCAA Collaboration for Advanced Instrument Development and Scientific Discoveries.
- Grants to develop Optical Telescope Integral Field Spectrograph (DOTIFS) for Devasthal, ARIES, Nainital, India, and Korea Institute of Advanced Studies, Seoul, South Korea.
- Grant to develop Robotic Adaptive Optics (RoBoAO) for California Institute of Technology, USA.
- Grants to develop Wide Area Linear Optical Polarimeter (WALOP) for Institute of Plasma Physics, Crete, Greece, and South African Astronomical Observatory, Cape Town.
- Grant to develop Detector Controller and Data Handling System for MIRADAS, University of

Florida, USA.
- Grant to develop Large Binocular Telescope Interferometer for LBT Observatory, University of Arizona, USA.

Kanak Saha

- CEFIPRA Grant for the project: The Assembly History of Disk Galaxies over the Last 8 Billion Years.
- DST Indo – South Africa Grant for the project: Galaxy Evolution: Simulation, Observation and Data Analysis under Enhanced Exchange Programme.

Varun Sahni

- DST J.C. Bose Fellowship.

Durgesh Tripathi

- Indo – German Max – Planck Partner Group Research Grant.

OTHER GRANTS TO IUCAA

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

RESEARCH AT IUCAA

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Quantum Theory and Gravity

Exploring the Rindler vacuum and the Euclidean plane

In flat spacetime, two inequivalent vacuum states which arise naturally are the Rindler vacuum $|\mathcal{R}\rangle$ and the Minkowski vacuum $|\mathcal{M}\rangle$. One can then build standard QFT based on these two vacua and study their inter-relationship. In particular, one can study Minkowski and Rindler Feynmann-propagators $G_{\mathcal{M}}(x_2, x_1)$ and $G_{\mathcal{R}}(x_2, x_1)$, respectively, defined by the standard procedure. It is well known that the Minkowski propagator $G_{\mathcal{M}}$ can be thought of as a 'thermalised' version of the Rindler propagator $G_{\mathcal{R}}$ in the following sense:

$$G_{\mathcal{M}}(i\tau) = \sum_{n=-\infty}^{\infty} G_{\mathcal{R}}\left(i\tau + i\,2\pi n\, g^{-1}\right), \tag{1}$$

where τ denotes the Rindler time coordinate and g is the acceleration parameter, which is taken to be unity henceforth. There is, however, another intriguing relationship between $G_{\mathcal{M}}$ and $G_{\mathcal{R}}$, which has received very little attention in the literature. It turns out that, for events (x_1, x_2) in the right-Rindler wedge, Candelas and Raine (1976) showed there was a curious relation between $G_{\mathcal{R}}$ and $G_{\mathcal{M}}$ given by:

$$G_{\mathcal{R}}(x_1, x_2) = G_{\mathcal{M}}[\sigma(x_1, x_2)] - \int_{-\infty}^{\infty} d\lambda\, \frac{G_{\mathcal{M}}[\sigma(x_1, x_2^{(r)}(\tau_2 - \lambda))]}{\pi^2 + (\lambda - \tau_1)^2}, \tag{2}$$

where $\sigma^2(x, y)$ is the square of the invariant distance between the two events, and the event $x_2^{(r)}(\tau)$ is defined through the relation $x_2^{(r)}(\tau) = x_2(\tau \pm i\pi)$. Geometrically, one can interpret $x_2^{(r)}(\tau)$ as the 'reflection' of $x_2(\tau)$ about the origin of the $x - t$ plane, as shown in Fig.1.

The original derivation of Eq.2 makes use of the fact that $G_{\mathcal{R}}$ and $G_{\mathcal{M}}$ are the Feynman propagators in the two vacua $|\mathcal{R}\rangle$ and $|\mathcal{M}\rangle$, respectively. It was not clear whether the same relation holds for a much wider class of functions, and if so, what are the essential ingredients which go into this relation. In this work, two functions $\{F_{\mathcal{R}}(\tau), F_{\mathcal{M}}(\tau)\}$, such that $F_{\mathcal{M}}$ is the periodic sum of $F_{\mathcal{R}}$ in the sense of Eq.(1) are considered. When both these functions are even, **Karthik Rajeev** and **T. Padmanabhan** showed that an integral transformation exists, which express $F_{\mathcal{R}}$ in terms of $F_{\mathcal{M}}$ and hence, can be interpreted as the 'inversion' of the thermal sum. This transformation is given by:

$$F_{\mathcal{R}}(z) = \int_{\mathcal{C}} \frac{du}{(i\pi)} \left[\frac{u}{(u^2 - z^2)}\right] F_{\mathcal{M}}(u), \tag{3}$$

where the contour is $\mathcal{C}$ shown in Fig.2. Further, they showed that for real values of z, this integral transformation reduced to a relation between $F_{\mathcal{R}}$ and $F_{\mathcal{M}}$, which has exactly the form of Eq.2. This result has the physical consequence that Feynman propagators of appropriate vacua in a general spacetime with a bifurcate killing horizon, whose explicit expressions may even be unknown, simultaneously satisfy equations analogous to Eq.1 and Eq.2.

Euclidean quantum field theory serves a useful mathematical tool to calculate important physical quantities in the real-world Lorentzian quantum field theories. In this work, **Karthik** and **Padmanabhan** clarified an important issue related to the Euclidean to Lorentzian continuation of points in Minkowski spacetime, namely, that the analytic continuation of the Euclidean polar coordinates — which involves replacing $t_E \to -it$ and $\tau_E \to -i\tau$ in $x = \rho\cos\tau_E, t_E = \rho\sin\tau_E$ — would lead us only to the events in the right-Rindler wedge. The question arises as to how one

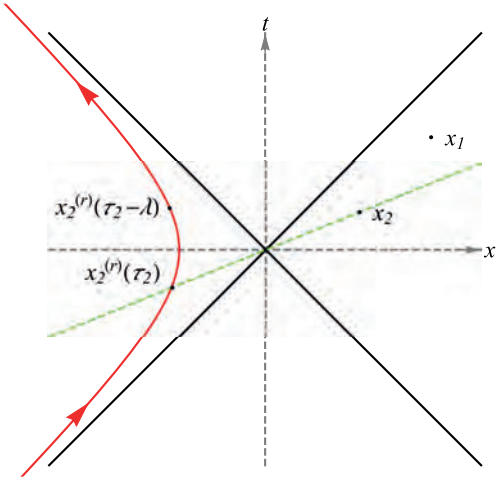


Figure 1: The geometric interpretation of the relation between $x_2^{(r)}$ and x_2.

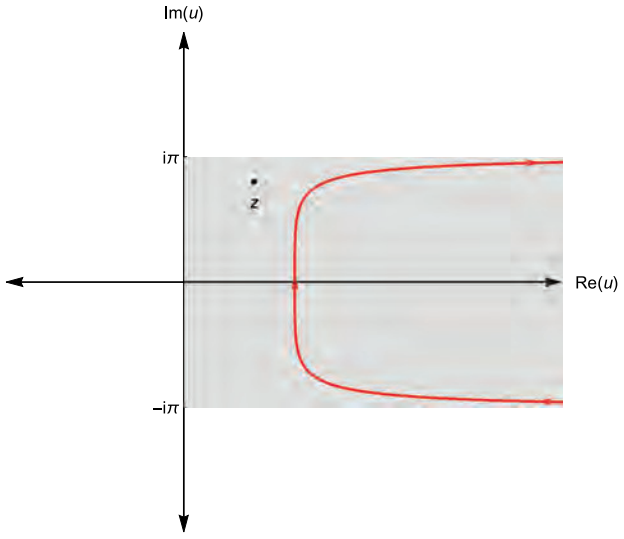


Figure 2: The contour $\mathcal{C}$ used in Eq.(3).

can extract the information contained in the other four wedges of the Lorentzian sector from the expression valid in the Euclidean sector. In this work, they provided the four different analytic continuations (see Tab.1) of the Euclidean polar coordinates such that one can reach all the four wedges in the Lorentzian sector from the Euclidean Rindler spacetime. The procedure is based on a simple unifying principle, viz, that the analytic continuation should map Euclidean squared distance σ_E^2 to $(\sigma_M^2 + i\epsilon)$, with a positive, infinitesimal, imaginary part in the Lorentzian sector. The authors explicitly demonstrate that this procedure leads to the correct expressions for the propagators in the Lorentzian sector, even when the two events are in two different wedges.

Case	Euclidean → Lorentzian	$\sigma_E^2 \to \sigma^2$
RR	$(r,\theta) \to (\rho, i\tau e^{-i\epsilon})$ $(r'\theta') \to (\rho', i\tau' e^{-i\epsilon})$	$\rho^2 + \rho'^2 - 2\rho\rho' \cosh(\tau - \tau') + i0^+$
RF	$(r,\theta) \to (\rho_R, i\tau_R)$ $(r',\theta') \to (i\rho_F, i\tau_F + \frac{\pi}{2} + \epsilon)$	$-\rho_F^2 + \rho_R^2 - 2\rho_F\rho_R \sinh(\tau_F - \tau_R) + i0^+$
FF	$(r_<,\theta) \to (-e^{i\epsilon} i\rho_<, i\tau + \frac{\pi}{2})$ $(r_>,\theta') \to (i\rho_>, i\tau' - \frac{\pi}{2})$	$-\rho_<^2 - \rho_>^2 + 2\rho_<\rho_> \cosh(\tau - \tau') + i0^+$

Table 1: Recipe for analytic continuation: Here R, L and F denotes the right, left and future Rindler wedges, respectively. The notation RR denotes the case when both points at which the propagator is evaluated lies in R, while RF denotes the case when one point is in the right and other in the future wedge, and so on. (r,θ) are the Euclidean polar coordinates and (ρ,τ) the corresponding Rindler coordinates, with the subscripts indicating the appropriate wedges.

Complex time route to quantum backreaction

When the degrees of freedom of a system can be naturally divided into two subsystems, say C and q, apart from the classical limit (viz. the $\hbar \to 0$ limit), one can also study another useful limit. This corresponds to the limit in which one subsystem, say C, is effectively classical, while the other is quantum mechanical. In the study of such systems, quantum backreaction refers to the correction to classical dynamics of the subsystem C due to the feedback from the quantum excitations of q.

One approach towards studying backreaction equation, that is often discussed in the literature, uses an effective action $S_{eff}[C]$ for the system C obtained by 'integrating out' the quantum degree of freedom q. To obtain the dynamical equation that describes the backreaction on the system C, we may demand that $\delta \mathrm{Re}[S_{eff}]/\delta C = 0$ for the effective classical 'trajectory' $C(t)$. Unfortunately, there are some severe issues in this approach: (i) the backreaction equation is non-causal, and (ii) the dynamics of C obtained by this approach does not seem to completely incorporate the effects of particle production. The origin of these undesired features is the presence of matrix element of operators acting on the Hilbert space of q-subsystem evaluated between the 'in-vacuum' and the 'out-vacuum'. The 'in-in' approach, where the 'in-out' matrix elements are replaced by 'in-in' expectation values, is devoid of the issues (i) and (ii). The main drawback concerning the 'in-in' prescription is that the manner in which one has to postulate – rather than derive– the backreaction equation is ad hoc.

In this work, **Karthik Rajeev** illustrated how the 'in-in' prescription could be given a path integral basis. For this purpose, he considered a $C-q$ system described by the following Lagrangian:

$$\mathcal{L} = \frac{m(C)}{2}\left[\dot{q}^2 - \omega^2(C) q^2\right] + M\left[\frac{\dot{C}^2}{2} - V(C)\right]. \tag{4}$$

He then formulated a path integral based effective action $S_{eff}^{\mathcal{T}}$ for time evolution along a general complex-time contour $\mathcal{T}$. When the evolution is along the $\mathcal{T}_1$ of Fig.3, the corresponding back reaction equation, obtained by varying the effective action $S_{eff}^{\mathcal{T}_1}[C]$, matches exactly with that of the 'in-out' formalism. On the other hand, for the choice of time-contour $\mathcal{T}_2$ of Fig.4, the backreaction

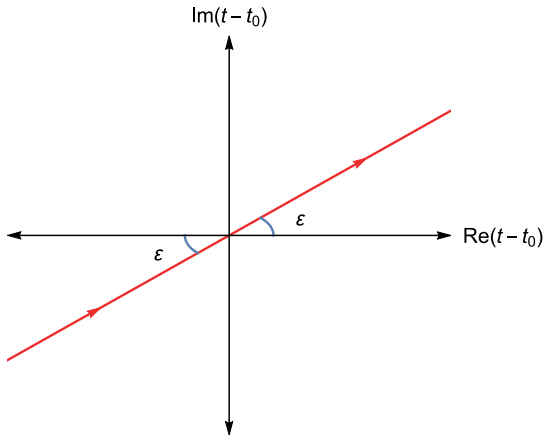


Figure 3: $\mathcal{T}_1$: The natural complex time contour that is relevant in the 'in-out' formalism.

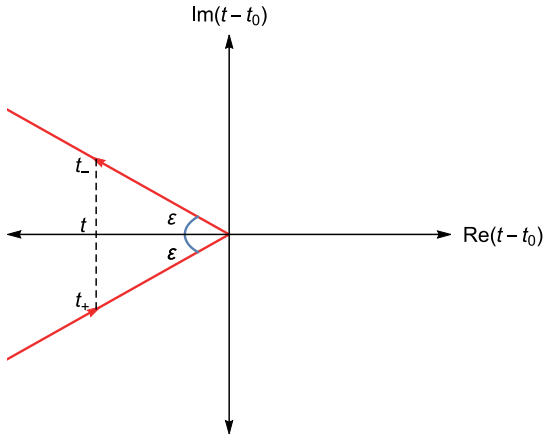


Figure 4: $\mathcal{T}_2$: The natural complex time contour that is relevant in the 'in-in' formalism.

obtained by varying the corresponding effective action $S^{\mathcal{T}_2}_{eff}[C]$ turns out to be precisely that of the 'in-in' formalism.

Therefore, one obtains a path integral based approach for deriving the correct backreaction prescription, which: (i) is causal and (ii) has the effect of particle production correctly taken into account.

Cosmology and Structure Formation

Primordial black holes from a tiny bump or dip in the inflaton potential

The existence of primordial black holes (PBHs) has been a subject of considerable interest ever since this possibility was suggested by Zeldovich and Novikov in 1967. Subsequently Hawking (1974) showed that quantum evaporation would leave behind PBHs with masses greater than about 10^{15}g, smaller black holes having completely evaporated by the present epoch. Interest in PBHs grew quite rapidly following these two seminal papers. It was soon realized that PBHs created in the early history of our universe could be of considerable importance since they might:

1. Seed the formation of supermassive black holes (BHs) in the nuclei of galaxies and AGN's.
2. Influence the ionization history of the universe.
3. Contribute to the dark matter (DM) density in the universe.

One might add that since particle dark matter in the form of WIMPs or an axion has not yet been compellingly discovered either by accelerator experiments or by direct DM searches, the possibility that a significant component of DM may consist of primordial black holes presents an entirely plausible and even alluring possibility.

Interest in PBHs received a major boost with the discovery by LIGO of gravitational radiation from merging BHs (event GW150914) with a mass of about $30M_\odot$. This discovery was supported by additional events, and at the time of writing, the number of black hole merger events exceeds ten, with many more expected to follow from future runs of LIGO, Virgo and KAGRA.

The precise physical mechanism responsible for PBH formation has been a subject of considerable debate. Early models of PBH production included: formation during bubble collision in a first order phase transition, the collapse of topological defects such as domain walls and cosmic strings, etc. Within the context of inflation, it was suggested that an enhancement of perturbations leading to PBH formation would occur if the inflationary spectrum had a significant blue tilt and/or non-Gaussianity, or if the inflaton rolled extra slowly for a duration of time which was much shorter than the full inflationary epoch.

In the context of single-field models, PBHs can form if the potential contains a near inflection point, or a saddle type region, which slows the motion of the inflaton field and leads to a spike in the perturbation spectrum.

Alternatively, the inflaton can also slow down by climbing a small local bump-like feature in the base inflationary potential. As demonstrated by **Swagat Mishra** and **Varun Sahni** by locally slowing the motion of the scalar field, the bump behaves like a speed-breaker and leads to a sharp increase in the amplitude of the curvature perturbation $\mathcal{R}$. An interesting example of a local speed-breaker arises if a term such as $V_b(\phi)\varepsilon(\phi)$ ($\varepsilon \ll 1$), localised at $\phi = \phi_0$, is added to the base inflationary potential $V_b(\phi)$. Applying this simple prescription with a Gaussian speed-breaker $\Delta(\phi - \phi_0)$ to the string theory based KKLT model and to α-attractor potentials, the authors find a sharp local enhancement of primordial perturbations at ϕ_0, which can result in a significant abundance of PBHs at the present epoch. The local nature of the speed-breaker permits the generation of PBHs in a wide mass ranging from the ultra-light 10^{-17} $M_\odot$ to the super-heavy 10^2 $M_\odot$ without significantly affecting the scalar spectral index n_s and the tensor-to-scalar ratio r on scales measured by the Cosmic Microwave Background (CMB). This stands in marked contrast

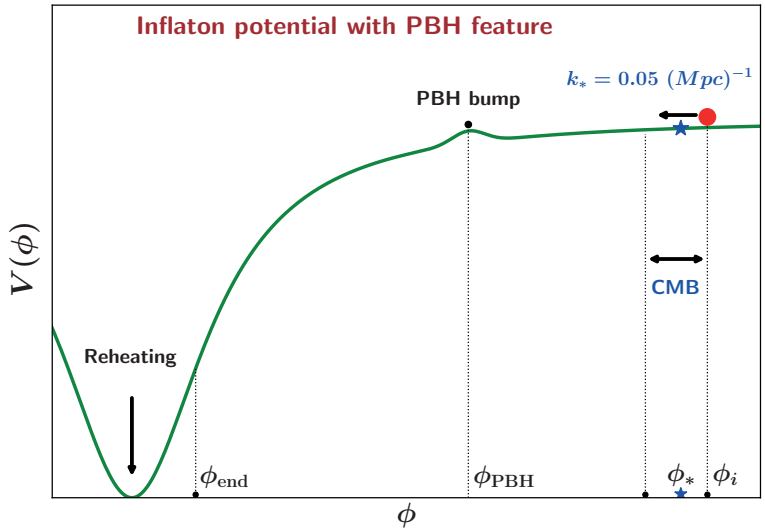


Figure 5: Inflaton potential with a primordial black hole feature in the form of a local bump superimposed on it. The feature arises at an intermediate scalar field value $\phi_{\rm PBH}$ before the end of inflation $\phi_{\rm end}$. Note that the bump size is shown significantly amplified for the purposes of illustration.

to 'near inflection point' scenarios which have difficulty in producing large mass PBHs without introducing a significant red tilt into the primordial perturbation spectrum on CMB scales.

Interestingly, a tiny local dip-like feature, which originates when a term such as $V_b(\phi)\varepsilon(\phi)$ ($\varepsilon \ll 1$), localised at $\phi = \phi_0$, is subtracted from the base inflationary potential $V_b(\phi)$, also serves the purpose of PBH formation. Therefore, a general potential capable of generating PBHs becomes:

$$V(\phi) = V_b(\phi)\left[1 \pm \varepsilon(\phi)\right], \tag{5}$$

where V_b is the base inflationary potential. The inflaton slows down while surmounting the bump/dip, resulting in the amplification of the scalar power spectrum and the production of PBHs. As demonstrated by **Mishra** and **Sahni**, both bumps and dips in the inflaton potential can successfully generate PBH's in a variety of mass-ranges (see Fig. 5).

In the standard single field inflationary paradigm, inflation is sourced by a minimally coupled canonical scalar field ϕ with a suitable potential $V(\phi)$. The background evolution of the scalar field is given by :

$$\ddot{\phi} + 3\,H\dot{\phi} + V'(\phi) = 0\ . \tag{6}$$

The extent of inflation is indicated by the total number of e-foldings during inflation:

$$\Delta N_e = N_e^i - N_e^{\rm end} = \log_e \frac{a_{\rm end}}{a_i} = \int_{t_i}^{t_{\rm end}} H(t)dt, \tag{7}$$

where $H(t)$ is the Hubble parameter during inflation. N_e denotes the number of e-foldings before the end of inflation so that $N_e = N_e^i$ corresponds to the beginning of inflation, while $N_e = N_e^{\rm end} = 0$ corresponds to the end of inflation.

The slow-roll phase of inflation, ensured by the presence of the Hubble friction term in the equation (6), is usually characterised by the first two Hubble slow-roll parameters ϵ_H, η_H,

$$\epsilon_H = -\frac{\dot{H}}{H^2}\ , \quad \eta_H = -\frac{\ddot{\phi}}{H\dot{\phi}} \tag{8}$$

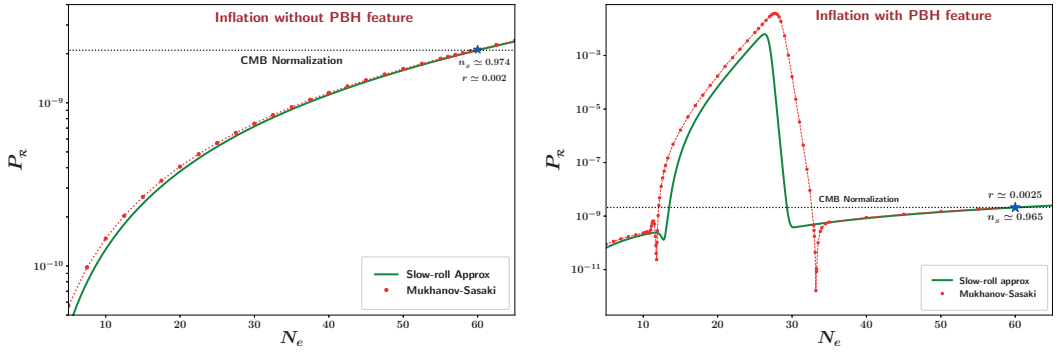


Figure 6: **Left panel**: The scalar power spectrum $P_\mathcal{R}$ is determined: (a) by using the slow-roll approximation (10) (solid green), and (b) by numerically solving the Mukhanov-Sasaki equation (red dots) for the base KKLT inflation potential (11). $P_\mathcal{R}$ is plotted as a function of the number of e-folds before the end of inflation N_e. Note that both methods give identical results for a smoothly varying potential, in which case $P_\mathcal{R}$ decreases monotonically with decreasing N_e. **Right panel**: Shows the plot of the scalar power spectrum during the formation of 10^{-13} $M_\odot$ PBHs in our model. This panel demonstrates that the slow-roll formula (10), shown in solid green, miscalculates the amplitude as well as the peak position of $P_\mathcal{R}$. Therefore, one must numerically solve the Mukhanov-Sasaki equation (dotted red) in order to compute $P_\mathcal{R}$ accurately.

where

$$\epsilon_H,\ \eta_H \ll 1\ , \tag{9}$$

during the slow-roll regime, in which scalar field perturbations are usually quantified in terms of the comoving curvature perturbation $\mathcal{R}$ and its power spectrum:

$$P_\mathcal{R} = \frac{1}{8\pi^2}\left(\frac{H}{m_p}\right)^2 \frac{1}{\epsilon_H}\ . \tag{10}$$

One finds that a decrease in the value of the slow roll parameter ϵ_H as the scalar field surmounts the bump (speed-breaker) in its potential leads to a corresponding increase in the amplitude of the power spectrum (10). This has been illustrated in Fig. 6.

A more accurate determination of $P_\mathcal{R}$ is provided by solving the Mukhanov-Sasaki equation. **Mishra** and **Sahni** have solved this equation to determine the black hole abundance in a class of inflationary models including KKLT inflation, which has the base potential:

$$V_b(\phi) = V_0 \frac{\phi^n}{\phi^n + M^n}\ , \tag{11}$$

supplemented by a speed-breaker in the form of a local Gaussian bump:

$$\varepsilon(\phi) = A \exp\left[-\frac{1}{2}\frac{(\phi-\phi_0)^2}{\sigma^2}\right]\ , \tag{12}$$

which is characterised by its height A, position ϕ_0 and width σ.

Note that $V(\phi)$ is characterized by 4 parameters $\{V_0,\ A,\ \phi_0,\ \sigma\}$. Since V_0 fixes the overall CMB normalization, only three parameters $\{A,\ \phi_0,\ \sigma\}$ are relevant for PBH formation. A speed-breaker consisting of a tiny bump of height $A \ll 1$ slows down the inflaton field sufficiently to enhance the scalar power spectrum relevant for PBH formation as shown in Figs. 6 and 7. Thus, the existence of black holes in the universe need not be attributed entirely to dying massive stars, black holes of a primordial origin could also contribute substantially to the black hole abundance today.

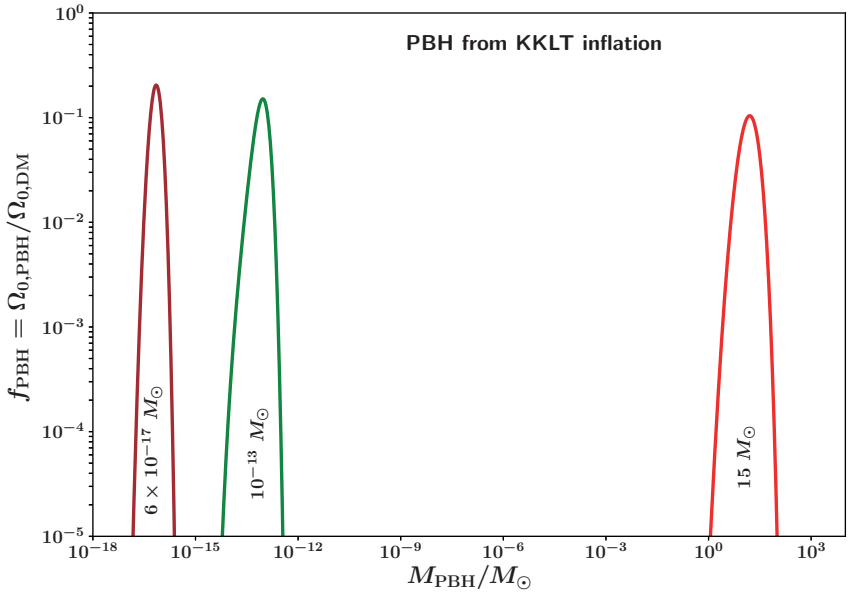


Figure 7: The fractional abundance of primordial black holes is shown as a function of PBH mass in the KKLT model for three differently located bumps. One sees that KKLT inflation with a tiny bump can generate nearly monochromatic narrow band mass functions, corresponding to 6×10^{-17}, 10^{-13} and 15 $M_\odot$ black holes. PBHs in these bands can contribute significantly to the dark matter density in the universe today.

Voronoi volume function: A new probe of cosmology and galaxy evolution

Aseem Paranjape and Shadab Alam (Royal Observatory, Edinburgh) have proposed the Voronoi volume function, (VVF) described below, as a novel probe of cosmology and structure formation. For a collection of points in space, such as the locations of tracers like galaxies or dark matter haloes, the Voronoi tessellation is a unique partitioning of space into cells such that (a) each cell contains a single tracer, and (b) any point in a cell is closer to the tracer contained in that cell than to any other tracer in the set. The Voronoi tessellation has a long history of applications in many scientific fields, including cosmology and large-scale structure, where it has been previously used in void-finding algorithms and numerical simulation techniques. The VVF proposed by **Paranjape** and Alam is simply the distribution of cell volumes of the Voronoi tessellation of any given set of galaxies or galaxy-like objects.

They show that the shape of the VVF of such tracers responds sensitively to physical properties such as mass, large-scale environment, sub-structure and redshift-space effects, making this a hitherto unexplored probe of both primordial cosmology and galaxy evolution. Using convenient summary statistics the width, median and a low percentile of the VVF as functions of tracer number density, they explore these effects using tessellations of tracers (specifically, dark matter haloes) identified in a suite of N-body simulations of a range of dark matter models. They find that the summary statistics are sensitive probes of primordial features such as small-scale oscillations in the initial matter power spectrum (as arise in models involving collisional effects in the dark sector), while being largely insensitive to a truncation of initial power (as in warm dark matter models). For vanilla Cold Dark Matter (CDM) cosmologies, the summary statistics display strong redshift evolution and redshift-space effects, and are also sensitive to cosmological parameter values for realistic samples. Comparing the VVF of galaxies in the GAMA survey with that of abundance matched CDM (sub)haloes tentatively reveals environmental effects in GAMA beyond halo mass. Their exploratory analysis, thus, paves the way for using the VVF as a new probe of galaxy evolution

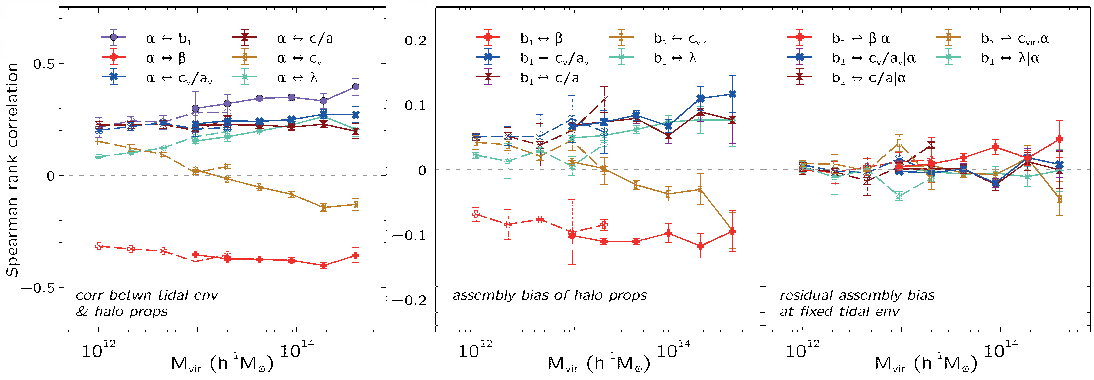


Figure 8: **Correlations between internal halo properties, tidal environment and large-scale bias.** (Left Panel:) Spearman rank correlation coefficients, for haloes in bins of mass $M_{\rm vir}$, between tidal anisotropy and other halo properties. In the legend, each coefficient γ_{ab} is represented by the symbol $a \leftrightarrow$b. (Middle Panel:) Assembly bias trends seen using Spearman rank correlation coefficients γ_{bc} between halo bias b and each internal property c. (Right Panel:) Conditional correlation coefficients $\gamma_{b_1 c|\alpha}$ for each internal property c. Note that the vertical axis in the middle and right panels is zoomed in by a factor ~ 3 as compared to the left panel. The right panel shows the main result of this work: each conditional coefficient $\gamma_{b_1 c|\alpha}$ is substantially smaller in magnitude than the corresponding unconditional coefficient $\gamma_{b_1 c}$ in the middle panel. Thus, conditioning on tidal anisotropy α largely accounts for the assembly bias trend of all internal halo properties.

physics as well as the nature of dark matter and dark energy.

Halo assembly bias and cosmic web tidal anisotropy

In the hierarchical ΛCDM universe paradigm, galaxies are believed to form within virialized dark matter haloes which merge to form larger ones. Understanding the properties of haloes is, therefore, crucial when one makes predictions for galaxy formation and infer the cosmology from observations. Galaxies and their host haloes are embedded in the large scale structure of the universe known as the cosmic web. This refers to the accumulation of matter into nodes, sheets and filament-like structures leaving behind vast expanses of underdense voids. The web environment of these haloes plays an important role in determining its late-time properties like angular momentum, shape and spin. This could be because haloes experience strong tidal forces and mass inflow rates in anisotropic environments like filaments as compared to more isotropic ones like the centre of a node, thereby affecting their internal properties. The web environment of a halo is quantified in this work by tidal anisotropy α, which is constructed with the tidal tensor. The clustering also seem to correlate with halo properties like formation time, concentration, sub-structure content, spin, shape, velocity dispersion and anisotropy. The dependence of halo clustering on a second property of the halo in addition to mass is now generally referred to as Assembly Bias (AB).

The AB is interesting to look at for several reasons. It would help in understanding the physics of structure formation. In the context of galaxy formation, the simplest empirical models link galaxy properties to halo masses alone, so it is interesting to look at what imprints AB leaves on galaxy properties. AB tells us that the large scale clustering some how determines the smaller scale internal properties of the halo. Here, **Sujatha Ramakrishnan**, **Aseem Paranjape**, Oliver Hahn and Ravi Sheth question whether this could be because of their mutual dependence on a third intermidiary scale property. This is done by taking the example of a few halo properties, and statistically show that halo AB is largely caused due to tidal anisotropy of the environment. This is done with the help of analysing N-body simulations and measuring halo properties such as shape, dispersion and anisotropy in velocity, spin and concentration. Then, the correlations which exist between halo internal properties and large scale clustering properties are studied to find that it is possible to statistically reduce this correlation when the anisotropy of the tidal environment is kept fixed. Fig. 8 summarises the main result. From this, **Ramakrishnan**, **Paranjape** and

collaborators establish the conditional independence of bias and internal properties of halo at fixed α, and conclude that the tidal anisotropy of the environment of the halo plays a significant role in shaping the internal properties as well as its correlations to the large scale clustering.

Observational Cosmology

Signatures of self-interacting dark matter on cluster density profile and sub-halo distributions

Currently astrophysical observations provide the best way to explore the particle physics properties of dark matter. Does dark matter have any interactions other than gravity? In this research work, by **Surhud More** and collaborators, large cosmological simulations were run including effects of different self-interactions of dark matter motivated from toy particle physics models. The focus of the study was to look at various observational properties of galaxy clusters such as the dependence on the number density profiles of satellite sub-halos and the density distribution of matter, in the presence of such interactions. It was shown that current weak lensing data can already put constraints on the self-interaction cross-section that are comparable to those obtained from the analysis of the Bullet Cluster.

The splashback radius of optically selected clusters with Subaru HSC second public data release

The edges of galaxy clusters, the so-called splashback radius, contain important information about how the galaxy clusters were assembled. The observed location of these edges in optically selected galaxy clusters, showed that they were about 20 percent smaller than expectations from the standard cosmological model. **Surhud More** and collaborators carried out research in which, the detection of the edges of galaxy clusters was extended to even earlier epochs in the Universe, as early as when it was just half its present age. This research made use of the data from the Subaru Hyper Suprime Cam survey. Tests on mock catalogues of galaxies showed that the new optical cluster finding algorithm used in the work was less susceptible to optical cluster selection effects.

On the measurements of assembly bias and splashback radius using optically selected galaxy clusters

The galaxy clusters selected from large imaging surveys have been previously used to detect the edges of galaxy clusters and to study the effect of halo assembly bias. In this research work, Tomomi Sunayama, a postdoc from Japan, in collaboration with **Surhud More**, critically examined the methodology behind these observational detections with the help of mock galaxy catalogues. They mimicked the optical cluster detection algorithms and applied them to these mock catalogues to show that the optical cluster finding algorithm can induce selection effects which cause one to infer the presence of halo assembly bias, even when the signal is explicitly erased in the mock catalogue. The work also showed that the projection effects induced by the optical cluster finding can bias the inference of the edges of galaxy clusters, and thus, appropriate caution is warranted before interpreting these observations done using optically selected galaxy clusters.

Kinematics of cluster galaxies and their relation to galaxy evolution

Surhud More and collaborators studied the kinematics of galaxies within massive clusters to probe the physics of quenching of star forming galaxies within galaxy clusters. It was shown using numerical simulations of dark matter, that the kinematics of satellite galaxies can provide information about galaxy infall that is complementary to the (instantaneous) spatial distribution of satellites. This kinematic information can help distinguish between models of galaxy quenching

that require intracluster processes from those that do not. Comparing the simulation results with measurements of real cluster galaxies, the research work presented evidence that the kinematics of red (quiescent) satellite galaxies are consistent with earlier infall times than that of blue (star-forming) satellites.

Cosmological constraints from cosmic shear two-point correlation functions with HSC survey first-year data

The gravitational lensing effect in the Einstein's general theory of relativity causes the shapes of background galaxies to get distorted due to the gravitational field of the intervening large scale structure. By measuring the exquisite images of about 9 million galaxies taken with the Subaru telescope using the Hyper Suprime-Cam (HSC) camera, the survey collaboration measured the weak lensing effect. The cosmic weak lensing shear two-point correlation functions were measured using data from the HSC survey first-year shear catalogue covering 137 sq deg of the sky. This study complemented the study performed the year before using power spectrum methods.

For a flat lambda-dominated cold dark matter model, the collaborators which included **Surhud More**, were able to constrain the amplitude of density fluctuations with an accuracy of 3.5 percent similar to that in the study using power spectrum methods. In comparison with Planck cosmic microwave background constraints, these results prefer slightly lower values of these amplitude of density fluctuations, although metrics such as the Bayesian evidence ratio test do not show significant evidence for discordance between these results. The ongoing full HSC survey data will contain several times more area, and will lead to significantly improved cosmological constraints.

SuGOHI-VI. Crowdsourced lens finding with Space Warps

The lens search was carried out, targeting massive galaxies, selected from over 442 square degrees of photometric data of the Hyper Suprime-Cam (HSC) survey using Space Warps, a citizen science project. Nearly 6,000 citizen volunteers participated in the experiment to inspect a sample of 300,000 galaxies. In parallel, **Anupreeta More** and collaborators used YattaLens, an automated lens finding algorithm, to look for lenses in the same sample of galaxies. Based on a statistical analysis of classification data from the volunteers and combined with lenses from YattaLens, they were able to find 14 definite lenses, 129 probable lenses, and 581 possible lenses. YattaLens found half the number of lenses discovered via crowdsourcing which is able to produce samples of lens candidates with high completeness and purity, compared to currently available automated algorithms. A hybrid approach, in which the visual inspection of samples of lens candidates pre-selected by discovery algorithms and/or coupled to machine learning is crowdsourced, will be a viable option for lens finding in the 2020s.

SuGOHI-V. Group-to-cluster scale lens search from the HSC-SSP survey

The largest sample of candidate strong gravitational lenses belonging to the survey of gravitationally lensed objects in Hyper Suprime-Cam Imaging for group-to-cluster scale (SuGOHI-c) systems are reported. **Anupreeta More** and collaborators visually inspected $\sim$ 39,500 galaxy clusters, selected from several catalogues spanning the cluster redshift range $0.05 < zcl < 1.38$. Over 640 candidate lens systems were discovered, of which 536 were new. From the full sample, 47 are almost certainly bonafide lenses, 181 of them are highly probable lenses, and 413 are possible lens systems. Additionally, 131 galaxy-scale lens candidates were serendipitously discovered during the inspection. Eight systems were spectroscopically confirmed as strong gravitational lenses. Since the HSC-SSP is an ongoing survey, it is expected to find $\sim$ 600 definite or probable lenses using this procedure and even more if combined with other lens finding methods.

SuGOHI-IV. Lensed quasar search in the HSC survey

Strong gravitationally lensed quasars provide a powerful means to study galaxy evolution and cosmology. **Anupreeta More** and collaborators use CHITAH, an algorithm to hunt for new lens systems, particularly lensed quasars, in the Hyper Suprime-Cam Subaru Strategic Program (HSC SSP) S16A. A sample of 46 lens candidates are presented, of which 3 are previously known. The six most promising candidates were confirmed with spectroscopy. The authors apply the software GLEE to model the six confirmed lenses uniformly. Through the analysis of the HSC images, it is noted that three systems appear to have point-like sources, which may or may not AGNs intrinsically. Using emission line widths and diagnostics, one of the sources was found to be a probable quasar and another source was found to be a Lyman-α emitter.

STRIDES: A 3.9 per cent measurement of the Hubble constant from the strong lens system DES J0408-5354

A blind time-delay cosmographic analysis for the lens system DES J0408-5354 is presented. This system is extraordinary for the presence of two sets of multiple images at different redshifts, which provide the opportunity to obtain more information at the cost of increased modelling complexity with respect to previously analyzed systems. **Anupreeta More** and collaborators combine the measured time delays, line-of-sight central velocity dispersion of the deflector, and statistically constrained external convergence with lens models to estimate two cosmological distances. The "effective" time-delay distance corresponding to the redshifts of the deflector and the lensed quasar and the angular diameter distance to the deflector, with covariance between the two distances, are measured. From these constraints on the cosmological distances, the Hubble constant is inferred to be $H_0 = 74.2 - 3.0 + 2.7 kms^{-1}$ Mpc^{-1} assuming a flat LCDM cosmology. This measurement gives the most precise constraint on H_0 to date from a single lens, which is consistent with measurements of H_0 based on the local distance ladder, reinforcing the tension with the inference from early universe probes, for example, with 2.2σ discrepancy from the cosmic microwave background measurement.

X-ray study of the double source plane gravitational lens system Eye of Horus observed with XMM-Newton

A double source plane (DSP) system is a precious probe for the density profile of distant galaxies and cosmological parameters. However, these measurements could be affected by the surrounding environment of the lens galaxy. Thus, it is important to evaluate the cluster-scale mass for detailed mass modelling. The Eye of Horus, a DSP system discovered by the Hyper Suprime-Cam Subaru Strategic Survey (HSC-SSP), was followed up with XMM-Newton. **Anupreeta More**, **Surhud More** and collaborators detected two X-ray extended emissions, originating from two clusters, one centred at the Eye of Horus, and the other located ∼100 arcsec north-east to the Eye of Horus. The dynamical mass assuming hydrostatic equilibrium was determined, and their contributions to the lens mass interior of the Einstein radius was evaluated. The contribution of the former cluster is $1.1^{+1.2}_{-0.5} \times 10^{12} M_{\odot}$, which is 21-76 per cent of the total mass within the Einstein radius. The discrepancy is likely due to the complex gravitational structure along the line of sight. On the other hand, the contribution of the latter cluster is only $\sim$ 2 per cent on the Eye of Horus. Therefore, the influence associated with this cluster can be ignored.

Discovery of an unusually compact lensed Lyman break galaxy from Hyper Suprime-Cam survey

HSC J0904-0102, a quadruply lensed Lyman-break galaxy (LBG) in the survey of gravitationally-lensed objects in Hyper Suprime-Cam Imaging (SuGOHI) has been reported by **Anupreeta More** and collaborators. Owing to its point-like appearance, the source was thought to be a lensed active

galactic nucleus. Follow up spectroscopy suggested that the foreground galaxy is a typical early-type galaxy at a high redshift of $z = 0.957$ with stellar velocity dispersion $\sigma = 259 \pm 56$ km s^{-1} and the lensed source is identified as an LBG at $z = 3.403$, based on the sharp drop bluewards of $Ly\alpha$ and other absorption features. A simple lens mass model for the system yields an Einstein radius of $R_{Ein} = 1.23$ arcsec and a total mass within the Einstein radius of $M_{Ein} = (5.550.24) \times 10^{11} M_{\odot}$ corresponding to a velocity dispersion of $\sigma = 283 \pm 3$ km s^{-1}, which is in good agreement with the value derived spectroscopically. In comparison with other lensed LBGs and typical $z \sim 4$ LBG populations, HSC J0904-0102 is unusually compact, an outlier at 2σ confidence. Together with a previously discovered SuGOHI lens, HSC J1152+0047, which is similarly compact, it is believed that the HSC survey will extend the LBG studies down to smaller galaxy sizes.

Lensed quasar search via time variability with the HSC transient survey

A new lens search algorithm was developed by **Anupreeta More** and collaboratos for four-image (quad) lensed quasars based on their time variability. A pipeline simulating multi-epoch images of lensed quasars in cadenced surveys, accounting for quasar variabilities, quasar hosts, lens galaxies, and the PSF variation is constructed. Applying the simulation pipeline to the Hyper-Suprime Cam (HSC) transient survey, an ongoing cadenced survey, HSC-like difference images of the mock lensed quasars are generated. Using the difference images of the mock lensed quasars and other variable objects from the HSC transient survey, their algorithm picks out variable objects as lensed quasar candidates based on their spatial extent in the difference images. The performance of their lens search algorithm is tested on a sample combining the mock lensed quasars and variable objects from the HSC transient survey. The lens search algorithm achieves a high true-positive rate (TPR) of 90.1% and a low false-positive rate (FPR) of 2.3% for the bright quads (the third brightest image brightness $m_{\rm third} < 22.0$ mag) with wide separation. With a pre-selection on the number of blobs in the difference image, a TPR of 97.6% and a FPR of 2.6% was obtained for the bright quads with wide separation. Even when difference images are only available in one single epoch, the lens search algorithm could still detect the bright quads with wide separation at high TPR and low FPR. Therefore, this algorithm is promising and could find new lensed quasars in ongoing and upcoming cadenced surveys, such as the HSC transient survey and the Large Synoptic Survey Telescope.

Extragalactic Astronomy

Formation of disk galaxies around z $\sim$ 2

Understanding the formation of disk galaxies like our Milky Way, Andromeda remains a challenging issue today. It is only in the last few years that cosmological simulations have started producing disk galaxies like ours, which can be followed up via zoom simulations to understand how disks grow over time. However, a number of questions remain to be answered; for example, when did disks start forming? What were the primary physical processes involved? At present, we lack adequate observational evidences to answer any of these questions. **Kanak Saha** and collaborators show some observational evidences on the epoch of disk formation based on Hubble Space Telescope (HST/WFC3) imaging data. A key component of this work has been a careful decomposition of a galaxy's light distribution into bulge and disk components for a sample of galaxies with redshifts ranging from $z = 1.5 - 4.0$. Such a decomposition provides us a categorised sample of pure spheroids (or bulge/elliptical like galaxies), pure disks and disk+bulge (two-components) systems (Fig. 9 shows an example of pure disk and two-component disk galaxies at $z = 2.81$). They found that two-component systems have increased from 46% at $z > 2$ to 70% at $z < 2$. Pure disks have grown substantially - both in size and mass while pure spheroids didnt evolve much across this redshift range. The same is true for the bulges residing in the two-component systems. They report substantial activity for the disk formation and its growth at around this redshift. This project has been in collaboration with Sonali Sachdeva, Rupjyoti Gogoi, **Ajit Kembhavi** and **Somak Raychaudhury**.

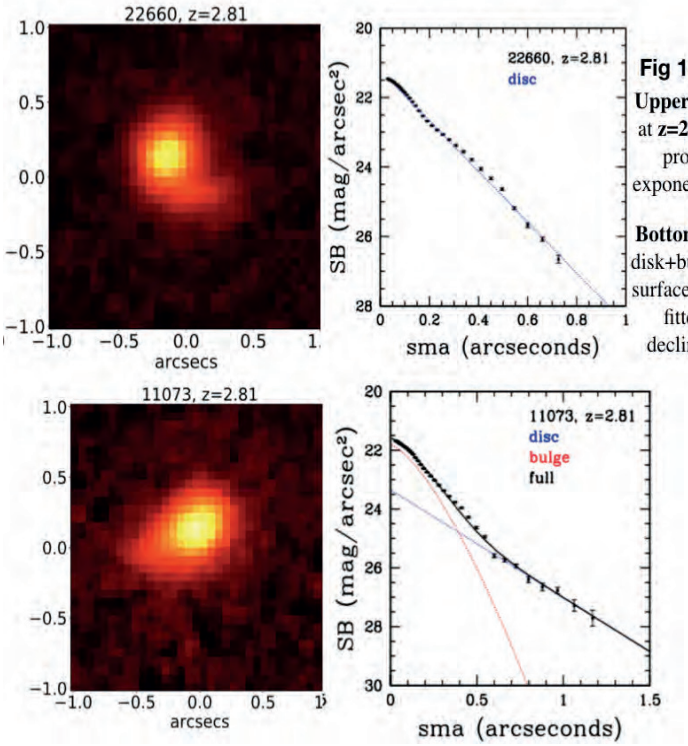


Fig 1:
Upper panel: Pure disk galaxies at **z=2.81**. Its surface brightness profile is well-fitted by an exponentially declining function.

Bottom panel: Two-component, disk+bulge galaxies at **z=2.81**. Its surface brightness profile is well-fitted by an exponentially declining profile plus a Sersic bulge

Figure 9: .

Narrowband Hα imaging of nearby Wolf-Rayet galaxies

The aim of this work is to explore the formation and evolution of Wolf-Rayet (WR) galaxies. The WR galaxies are subset of HII galaxies. They are classified based on broad optical emission features of HeII λ4686 and CIV λ5808 lines, originated in the stellar winds from a substantial population of WR stars. Thease features in WR galaxies are often seen after $2-5$ Myr of intitial star formation for a short duration (<0.5 Myr), until WR population end their lives in supernovae. Therefore, these galaxies are ideal systems to explore onset of star formation and its triggering mechanism.

Abhishek Paswan, Kanak Saha and Amitesh Omar studied using their own narrowband Hα imaging observations along with other archival data from GALEX, SDSS, IRAS, FIRST and NVSS surveys. Most of the galaxies show a morphological feature related to galaxy tidal interactions and mergers process (e.g., see Fig. 10). Here it is found that these WR galaxies have exprienced tidal interactions and/or mergers with low-luminous dwarf galaxy or HI cloud that most likely triggered the recent star formation in galaxies. These galaxies are further put in the main sequence (MS) relation (a relation between stellar-mass and star formation rate). They followed a similar MS relation as known for non-WR star-forming galaxies, suggesting that WR systems evolve in a similar fashion as normal star-forming galaxies evolve. In case of WR galaxies, it is, however, noticed that the scatter in the relation is comparitively higher than that of normal star-forming galaxies. It is mainly due to merging/interacting nature of the WR systems.

Incoherent fast variability of X-ray obscurers: The case of NGC 3783

Variation in absorption of X-ray radiation emitted from the Active Galactic Nuclei (AGN) is a phenomenon seen in the X-ray spectra of several active galaxies. Studying this phenomenon utilizing the high X-ray spectra from X-ray instruments and the computer simulations allow us to estimate the several physical properties of the variable ionized gas present in the vicinity of the super-massive

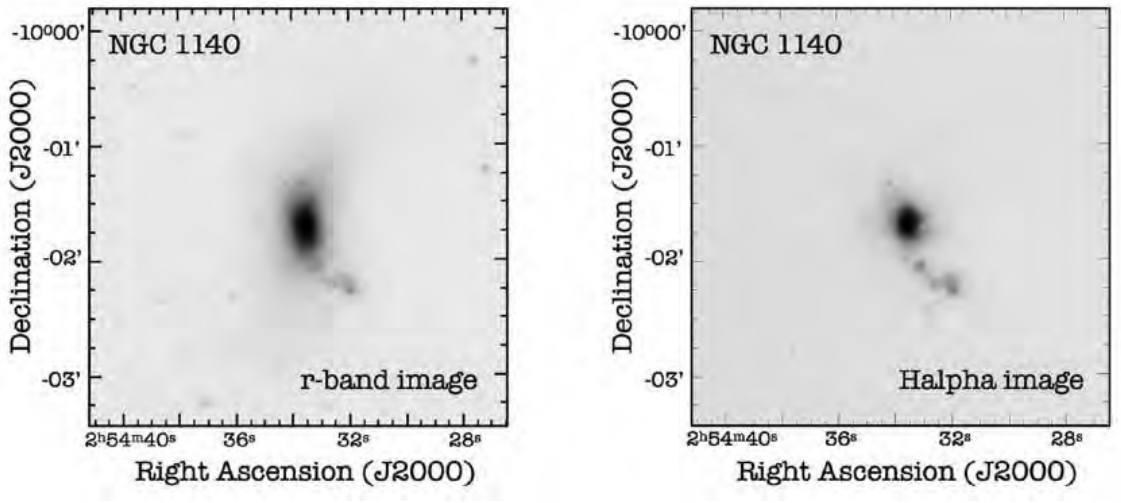


Figure 10: **Left:** The broad r-band image, tracing the stellar continnum light in the galaxy. **Right:** The stellar continuum subtracted Hα emission line image, tracing ionized gas or site of star-forming regions in the galaxy. (Both the images towards the south-west direction show a tidal tail like feature related to galaxy tidal interaction process)

black hole in AGN. **Tek. P. Adhikari,** and collaborators carried out a comparative analysis of X-ray spectrum of NGC 3783 during unobscured and obscured states observations. The study of spectral -timing properties of the X-ray obscurer in NGC 3783 enabled them to put independent constraints on the density and location of the obscuring gas.

What shapes the absorption measure distribution in AGN outflows?

The absorption measure distribution (AMD) in the X-ray outflows of Seyfert active galactic nuclei describes the distribution of absorbing column density as a function of ionization level of the gas. The shape of this distribution provides the information regarding the distribution of ionized materials in the environment of super-massive black hole. **T. P. Adhikari** and collaborators investigated such distribution and tested a range of photoionization models against the overall shape of the AMD as observed in Seyfert galaxies. In particular, they demonstrated that the shape of the distribution of ionized material is determined by both the spectral energy distribution (SED) of radiation that enters the material, and its density. The model that best follows the observed distribution of AMD is one wherein the gas density of the absorbing outflow is of the order of 10^{12} cm^{-3}, irradiated by an SED whose optical/UV power is 100 times higher than the X-ray power (see Fig. 11).

Galaxies

In order to understand the possible mechanisms of recurrent jet activity in radio galaxies and quasars, Sumana Nandi, **D.J. Saikia**, **Rupak Roy**, **Pratik Dabhade**, et al. have identified such sources with a large range of linear sizes (220 917 kpc), and hence time scales of episodic activity. They have presented high-sensitivity 607-MHz Giant Metrewave Radio Telescope (GMRT) images of 21 possible double-double radio galaxies (DDRGs) identified from the FIRST survey confirming their episodic nature. A new DDRG has been identified with a candidate quasar. The estimated age limits (11 52 Myr) are smaller than those of the large-sized ($\sim$ 1 Mpc) DDRGs.

The CHANG-ES galaxy sample consists of 35 nearby edge-on galaxies that have been observed

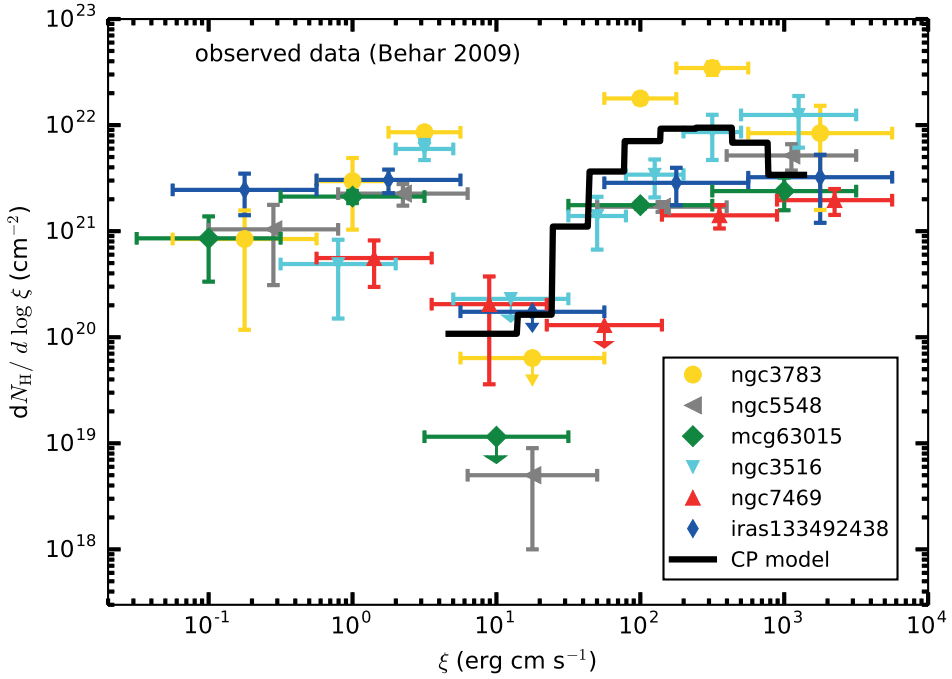


Figure 11: The best fit model of absorbing material distribution (shown by black histogram) over plotted with the points obtained from X-ray observations by Behar(2009) for six Sy1 galaxies. The best fit model infers the gas density $n_{\rm H} = 10^{12}$ cm^{-3}.

using the VLA at 1.6 and 6.0 GHz. The third data release of the sample, namely, the B configuration 1.6 GHz sample and spectral index maps between 1.6 and 6.0 GHz with a matched resolution of ~ 3 arcsec have been presented. The authors examine the possible presence of low-luminosity active galactic nuclei (AGNs) in the sample, as well as some in-disk structure. New features can be seen in the spectral index maps that are masked in the total intensity emission, including hidden spiral arms in NGC 3448 and two previously unknown radio lobes on either side of the nucleus of NGC 3628. The AGN detection rate, using only radio criteria, is $\sim$55%.

D.J. Saikia and collaborators present results of HI absorption experiment done using the GMRT towards 27 low- and intermediate-luminosity radio active galactic nuclei (AGNs), classified as either low excitation radio galaxies (LERGs) or high excitation radio galaxies (HERGs) and with WISE colour $W2[4.6\mu m]-W3[12\mu m] > 2$. They report HI absorption detection towards seven radio AGNs, six of which are new. Combined with other sources from the literature, they show that compact radio AGNs with WISE colour $W2 - W3 > 2$ have higher detection rates compared to those with $W2 - W3 < 2$. HI absorption detection rate is shown to be higher for HERGs compared to LERGs, mainly due to a larger fraction of HERGs being gas and dust rich with a younger stellar population and thus with $W2-W3 > 2$ compared to LERGs. The detection rates are similar for similar WISE colours $W2-W3 > 2$, implying detection of HI gas may not necessarily mean high excitation mode AGN. From an analysis of the kinematics, they find that LERGs show a significantly wider range in the shift of centroid velocities of the absorbing gas than HERGs possibly due to differences in jet-interstellar medium interaction.

Gravitational Waves

Optimal optical search strategy for finding transient in large sky error region under realistic constraints

Javed Rana, Shreya Anand, and **Sukanta Bose** developed this new method in multi-messenger astronomy. In order to identify the rapidly-fading, optical transient counterparts of gravitational wave (GW) sources, an efficient follow-up strategy is required. Since most ground-based optical observatories aimed at following-up, GW sources have a telescope with a small field-of-view (FOV) as compared to the GW sky error region, they focus on a search strategy that involves dividing the GW patch into tiles of the same area as the telescope FOV to strategically image the entire patch. They presented an improvement over the past optimal telescope-scheduling algorithms by combining the tiling and galaxy-targeted search strategies, and factoring the effects of the source air-mass and telescope slew, along with setting constraints, into the scheduling algorithm in order to increase the chances of identifying the GW counterpart. Using the observatory site of the GROWTH-India telescope as an example, they generated 100s of skymaps to test the performance of their algorithms. Their results indicate that slew-optimization can reduce the cumulative slew angle in the observing schedule by 100s of degrees, saving several minutes of observing time without the loss of tiles and probability. Further, they demonstrated that as compared to the greedy algorithm, the airmass-weighted algorithm could acquire up to 20% more probability and 30 sq. degree more in areal coverage for skymaps of all sizes and configurations.

Regularised map-making of a stochastic gravitational wave background

Estimating a map of the SGWB sky from noisy data is a challenging problem. This is becoming progressively relevant as the number of detectors are increasing and the existing ones are becoming more and more sensitive, and a detection of the isotropic background map happen in a few years time. Since the matrix that couples the true anisotropic sky to the data is ill conditioned, deconvolution of the observed map becomes more reliable when known features about the expected signal is incorporated in the process. S. Panda, Shweta Bhagawat, J. Suresh and **Sanjit Mitra** introduced a widely used procedure to incorporate these "priors" through a Bayesian regularization scheme in this context. They demonstrate that regularization significantly enhances the quality of reconstruction,

(see Fig. 12), especially when the intensity of the source is weak, and it dramatically improves the stability of deconvolution.

Effect of induced seismicity on advanced gravitational wave interferometers

Advanced LIGO and the next generation of ground-based detectors aim to capture a large number of binary coalescences through improving sensitivity and duty cycle. Earthquakes have always been a limiting factor at lower frequencies, where neither the pendulum suspension nor the active controls provide sufficient isolation to the test mass mirrors. Several control strategies have been proposed to reduce the impact of teleseismic events by switching to a robust configuration with less aggressive feedback. The continental United States has witnessed a huge increase in the number of induced earthquake events primarily associated with hydraulic fracking-related waste water re-injection. Effects from these differ from teleseismic earthquakes primarily because of their depth which is in turn linked to their triggering mechanism. N. Mukund, B. O'Reilly, S. Somala and **Sanjit Mitra** discuss the impact caused by these low magnitude regional earthquakes and explore ways to minimize the impact of induced seismicity on the detector.

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

Standard searches are currently restricted to the parameter space which assumes aligned spins. A larger parameter space allowing precession will entail far more number of templates escalating the computational cost. Optimising the consequential increase in false alarms poses a serious computational challenge. Bhushan Gadre, **Sanjit Mitra** and **Sanjeev Dhurandhar** propose here a hierarchical strategy to search for CBCs for a network of detectors. The methodology is essentially as follows: In the first step, a search with a coarse bank at low sampling rate is performed with a relatively low threshold and then the candidate triggers are followed up with a fine search with the requisite threshold. This method of search is more efficient. They demonstrate the computational advantage of about 20 over the usual search in real data. This saving in the computational cost will allow them to free up computational resources and time.

Optimal chi-square vetos for sine-Gaussian glitches

The traditional chi-square veto has been applied to the gravitational wave data with fair amount of success. However, this test is ad hoc and is not guaranteed to be optimal. In this work, R. Dhurkunde, P. Joshi, **Sanjeev Dhurandhar** and **Sukanta Bose** construct an optimal chi-square test for glitches in the data, which can be modelled as sine-Gaussians, because such glitches are ubiquitous in the data. The method for constructing any chi-square has been fully discussed in our previous work on unified chi-squares (**Sanjeev Dhurandhar**, et al., 2017). The parameter space of sine-Gaussians is adequately sampled and a vector space spanned by these sampled glitches is obtained. However, this space is very large from the computational point of view. By applying singular value decomposition techniques, it is possible to whittle down this space to a much lower dimensional subspace which best approximates the glitches. This procedure eventually leads to the required optimal chi-square for sine-Gaussian glitches.

Improving the anisotropic stochastic background search with a natural set of basis functions

The anisotropic stochastic background is estimated using the radiometric search, in which one cross-correlates the time series data from two detectors in short data segments, and then takes the noise weighted sum to arrive at a statistic. However, this statistic results in point spread function, which maps a point source to a diffused image. Therefore, the image obtained of any source is dirty

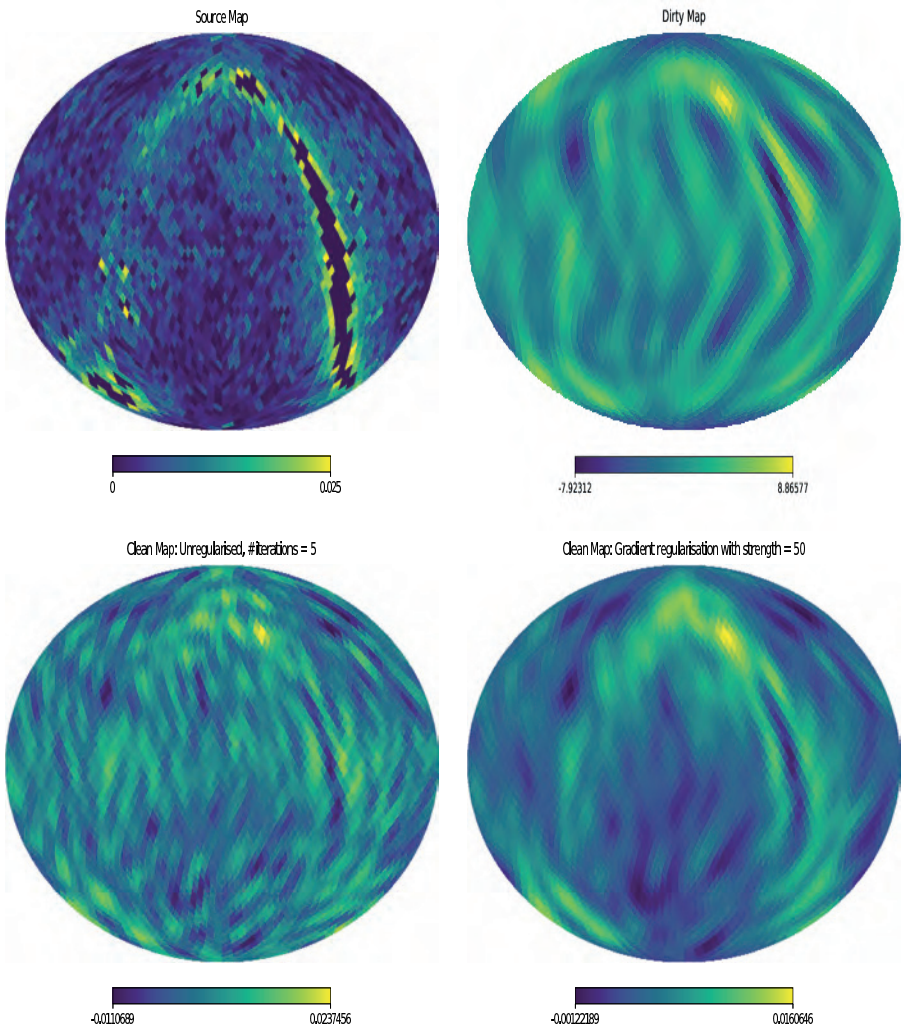


Figure 12: Demonstration of regularised deconvolution for a fiducial injected map (a) The raw 'dirty' map (b) is convolved with the antenna pattern functions of the detectors and needs to be deconvolved to estimate the true sky. Maximum likelihood estimation with the standard conjugate gradient method, that performs well in these situations, yields a noisy result. The Bayesian regularisation method, with a generic prior to prefer a smoother, less fluctuating, solution in this case, produces a much better match between the recovered and the injected map. The dirty map has poorer match with the source map for weak sources, especially for point like ones, which is why it is not optimal to use it directly without deconvolution. [Phys. Rev. D 100, 043541, arXiv:1905.08276 [gr-qc].]

and needs to be cleaned up by deconvolution. The deconvolution procedure involves the inversion of the beam matrix which is expressed in terms of basis functions. So far in the literature, two bases have been used: (i) the pixel basis, and (ii) the spherical harmonic basis. In this project, P. Upadhyaya, **Sanjeev Dhurandhar** and **Shivraj Kandhasamy** propose to explore a third basis which is natural to the problem - namely, the point spread functions themselves. The point spread functions are intersections of the sky sphere with cones determined by the baseline joining the detectors. We expect this approach to lead to an efficient handling of the problem.

Time-delay interferometry for LISA (Laser Interferometric Space Antenna)

The review article written by M. Tinto and **Sanjeev Dhurandhar** dated earlier of 2014 has been now updated after the discovery of gravitational waves. The update was necessary, because the design of LISA has changed in recent years for various reasons such as technological advances. The article now incorporates the changes from the current experimental design. On another front, more insights on the mathematics have been added, for example, how this work relates to the famous Hilbert's syzygy theorem, etc. Our current experience with real data from ground-based detectors has shown why it is important to adopt an approach in which the statistical constructs from the data analysis are free from singularities. The algebraic-geometric approach described in the article is inherently singularity free.

Cosmic Magnetic Fields

Characterising the dynamo in a radiatively inefficient accretion flow

The MRI driven dynamo in a radiatively inefficient accretion flow (RIAF) using the mean field dynamo paradigm was explored by Prasun Dhang, **Abhijit Bendre**, Prateek Sharma, **Kandaswamy Subramanian**. Using singular value decomposition (SVD), the least squares fitting dynamo coefficients α and γ were obtained, by comparing the time series of the turbulent electromotive force and the mean magnetic field. This study is the first one to show the poloidal distribution of these dynamo coefficients in global accretion flow simulations. Surprisingly, a high value of the turbulent pumping coefficient γ was obtained, which transports the mean magnetic flux radially outward. This would have implications for the launching of magnetised jets which are produced efficiently in presence a large-scale poloidal magnetic field close to the compact object. A scenario of a truncated disc beyond the RIAF, where a large scale dynamo-generated poloidal magnetic field can aid jet-launching close to the black hole was explored. Magnitude of all the calculated coefficients decreases with radius. Meridional variations of $\alpha_{\phi\phi}$, responsible for toroidal to poloidal field conversion, is very similar to that found in shearing box simulations using the 'test field' (TF) method. By estimating the relative importance of α-effect and shear, it was concluded that the MRI driven large-scale dynamo, which operates at high latitudes beyond a disc scale height, is essentially of the $\alpha - \Omega$ type.

Generation of large scale magnetic fields due to helicity and shear

Coherent large-scale magnetic fields and mean differential rotation are two common features of most astrophysical objects, such as the Sun, stars, galaxies, etc. Magnetic fields in these systems are maintained by turbulent dynamo action, where the standard paradigm for large-scale component involves amplification of weak seed fields due to helical turbulence in shear flows. The alpha-effect, which in idealized settings, is a measure of net kinetic helicity and arises naturally in systems with rotation and stratification, plays a crucial role in driving large-scale dynamos in a variety of systems.

In a recent work, **Nishant Singh**, together with Naveen Jingade, studied the mean field dynamo action in a background linear shear flow by employing pulsed renewing flows with fixed kinetic helicity and non-zero correlation time. They used plane shearing waves in terms of time-dependent

exact solutions to the Navier-Stokes equation as derived by Singh and Sridhar (2017), and determined the average response tensor governing the evolution of mean magnetic field. The growth rate and cycle period of the growing dynamo wave revealed new scaling relations with the shear rate. These have implications for magnetic activity cycles of stars in recent observations. Their study essentially generalizes the standard alpha-omega dynamo as also the alpha-effect is affected by shear and the modelled random flow has a finite memory.

The shear dynamo problem with a magnetic background

In recent years, the possibility of large-scale dynamo action through the shear-current effect in flows where more conventional dynamo effects, such as the alpha-effect arising through stratification and rotation, cannot operate, has gained a lot of interest. Latest work of **Nishant Singh** and his collaborators involved a study of shear-current effect in the presence of magnetized burgulence. The main purpose of this work was to check if recently claimed magnetic shear current effect could lead to dynamo growth. By measuring the turbulent transport coefficients, importantly the diffusivity tensor, using the non-linear test-field method, they found that the magnetic shear current effect is not operative in most cases which show a dynamo instability. Further analysis revealed that the main driver of the dynamo in those cases is the so-called incoherent-alpha shear mechanism in which alpha-coefficients are allowed to fluctuate about a zero mean.

High Energy Astrophysics

Polarisation measurements

Polarisation measurements of the prompt emission of 11 bright Gamma Ray Bursts detected during the first year of AstroSat operations have been presented by **Dipankar Bhattacharya**, **Vidushi Sharma** and collaborators. There were six detections and five upper limits, indicating a wide range in the degree of polarisation of the emission integrated over the burst. It appears likely that temporal averaging reduces the measurable polarisation in a significant number of GRBs. Time resolved analysis of one of the brightest events, GRB160821A, carried out by **Sharma**, **Bhattacharya**, **Shabnam Iyyani** and collaborators, revealed near-orthogonal transition of polarisation angle twice through the burst, accompanied by a change in spectrum. The observed behaviour indicates the presence of strongly ordered magnetic field in the emitting material.

AstroSat observation of an accreting black hole

Detailed AstroSat observations of an accreting black hole binary MAXI J1535-571 led to the discovery of a very strong correlation between the spectral slope and the frequency of quasi-periodic oscillation in the intensity of the X-ray radiation. This poses significant constraints on the origin of the observed X-ray emission, and suggests that a Comptonising region controls both the emergent spectrum and the intensity variations. This observation has been done by **Yash Bhargava**, **Dipankar Bhattacharya**, **Ranjeev Misra** and collaborators. AstroSat observations of another well-known black hole X-ray binary GRS 1915+105 by **Bhattacharya** and collaborators have showed, for the first time, a variation in the frequency of the ∼70 Hz quasi-periodic oscillation of its X-ray luminosity being correlated with the spectral state of the source

Sustained timing observations of eight radio pulsars with the Ooty Radio Telescope and the Giant Metrewave Radio Telescope by A. Basu, **Dipankar Bhattacharya** and collaborators revealed 11 incidents of sudden change in the spin frequency of these pulsars, called glitches. Three of these glitch events were new discoveries, the remaining being reported also from other observatories

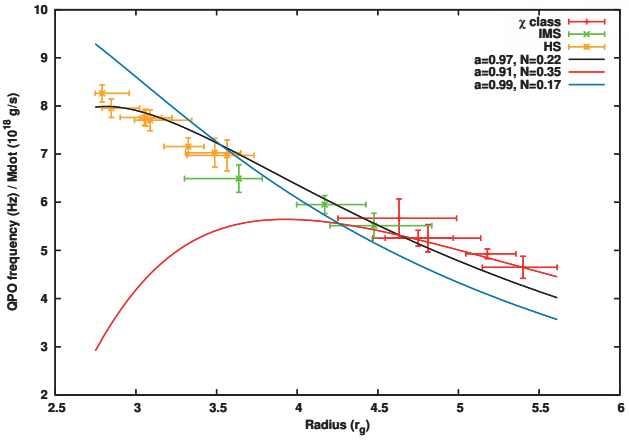


Figure 13: Variation of QPO frequency divided by the accretion rate with inner disk radii. The lines represent the predictions by the relativistic standard accretion disk model for dimensionless spin parameter a = 0.973 (best fit) and for comparison, a = 0.91 and 0.99.

AstroSat observations

AstroSat observed the galactic micro-quasar system GRS 1915+105 when the system exhibited C-type Quasi-periodic Oscillations (QPOs) in the frequency range of 2-6 Hz. For these observations, **Ranjeev Misra**, D. Rawat, J.S. Yadav and P. Jain showed that the broad band spectra (1-50 keV) obtained from simultaneous LAXPC and SXT, can be well described by a dominant relativistic truncated accretion disk along with thermal Comptonization and reflection. They found that while the QPO frequency depended on the inner radii with a large scatter, a much tighter correlation has been obtained when both the inner radii and accretion rate of the disk was taken into account (See Fig. (13). In fact, the frequency varies just as the dynamic frequency (i.e., the inverse of the sound crossing time) as predicted decades ago by the relativistic standard accretion disk theory for a black hole with spin parameter, a ~ 0.9. Thus, a general relativistic prediction has been tested using X-ray data analysis. This identification has been possible due to the simultaneous broad band spectral coverage with temporal information as obtained from AstroSat.

Comparative study of a sample of narrow-line and broad-line Seyfert 1

Vineet Ojha, Hum Chand, **Gulab C. Dewangan** and Suvendu Rakshit performed a detailed comparative systematic study of a sample of 221 narrow-line Seyfert 1 (NLSy1) galaxies in comparison to a redshift-matched sample of 154 Broad-line Seyfert 1 (BLSy1) galaxies based on ROSAT and XMM-Newton telescopes. Based on their homogeneous analysis, they investigated correlations between the soft X-ray spectral shape, Eddington ratios, bolometric luminosity, black hole masses, and the widths of the broad component of optical Hbeta line. They found clear evidence for the difference in the distributions of soft X-ray spectral shape and Eddington ratio among NLSy1 and BLSy1 galaxies, with steeper soft X-ray spectrum and higher Eddington ratio for the former. Such a difference also exists in the hard X-ray spectral index distribution. These results suggests that the higher Eddington ratio in NLSy1 is responsible for the steeper X-ray spectral slope compared to the BLSy1, consistent with the disc-corona model as proposed for the luminous AGNs.

Detection of a type C quasi-periodic oscillation

Swadesh Chand, Vivek Agrawal, **Gulab C. Dewangan** and P. Thakur reported the detection of a type C quasi-periodic oscillation (QPO) along with an upper harmonic in two observations of the low-mass black hole transient H 1743-322 jointly observed by XMM-Newton and NuSTAR

during the 2016 outburst. They found that the QPO and the upper harmonic exhibit shifts in their centroid frequencies in the second observation with respect to the first one. The hardness intensity diagram implies that in contrast to the 2008 and 2014 failed outbursts, the 2016 outburst was a successful one. They also detect the presence of a broad iron K alpha line near 6.5 keV and a reflection hump in the energy range 15-30 keV. Along with the shape of the power density spectra, the nature of the characteristic frequencies and the fractional rms amplitude of the timing features imply that the source stayed in the low/hard state during these observations. Moreover, the photon index and other spectral parameters also indicate the low/hard state behaviour of the source. Unlike the soft lag detected in this source during the 2008 and 2014 failed outbursts, the 2016 outburst showed hard time lags of $0.40 \pm 0.15s$ and 0.32 ± 0.07s in the 0.07-0.4 Hz frequency range. The high Comptonized fraction and the weak thermal component indicate that the QPO is being modulated by the Comptonization process.

Strong Xray excess in gamma-ray blazar OJ 287

Main Pal, Pankaj Kushwaha, **Gulab C. Dewangan** and **Pramod Pawar** reported a strong soft X-ray excess in the gamma-ray blazar OJ 287 during long exposure in 2015 May, among two of the latest XMM-Newton observations performed in 2015 and 2018 May. In the case of the 2015 May observation, a log parabola model is found to fit the EPIC-pn data well, while a log parabola plus a power law describes the overall simultaneous optical to X-ray spectra, suggesting the excess as the synchrotron tail. This interpretation, however, is inconsistent with the observed spectral break between near-infrared (NIR) and optical spectra, attributed to a standard disk around a supermassive black hole (SMBH). Based on this, they considered two commonly invoked accretion-disk-based models in active galactic nuclei (AGNs) to explain the soft excess: the cool Comptonization component in the accretion disk and the blurred reflection from the partially ionized accretion disk. They found that both cool Comptonization and blurred reflection models provide an equally good fit to the data, and favour a super-heavy SMBH of mass $\sim 10^{10} M_{\odot}$. Further investigation of about a month-long simultaneous X-ray and ultraviolet (UV) pointing observations revealed a delayed UV emission with respect to the 1.5 10 keV band, favouring X-ray reprocessing phenomenon as the dominant mechanism. The results suggest that the soft excess is probably caused by strong light bending close to the SMBH. The detected soft excess in the 2015 data and its disappearance in the 2018 data is also consistent with the presence of accretion-disk emission, inferred from the NIR-optical spectral break between 2013 May and 2016 March.

Disruption of massive star

Rupak Roy has been studying mainly the disruption of massive stars at the end of their life-time, known as Core-collapse Supernovae (CCSNe), disruption of stars through tidal forces of the Supermassive Black Holes (SMBHs) at the centers of the galaxies, known as Tidal Disruption Events (TDEs), and disruption of extremely massive stars, known as Superluminous Supernovae (SLSNe), observational aspects of extremely energetic outflows from AGNs, Radio Galaxies, etc.

The CCSNe events produce a compact remnant (neutron star or stellar-mass black Hole) due to the collapse of the stellar-core, and its outer material is ejected in the space. Since in the universe, except Hydrogen, almost all other elements are produced at the centers of the stars, and get ejected through stellar-eruptions or supernovae, and produce second-generation stars, study of the supernovae are extremely important to understand this feedback process. This is also important to study the shock physics of the extreme catastrophes and to know the nature of their progenitors. Recently, astronomers have also discovered stellar-disruptions, which are 10-100 times luminous than canonical CCSNe. These are called Superluminous Supernovae (SLSNe), physics of which is still unknown.

TDEs are the disruptions of stars by the supermassive black holes (SMBHs, mass $\sim 10^8$ $M_{\odot}$) at the centers of the galaxies. These extremely energetic phenomena (liberated energy $\sim 10^{50}$ ergs) exist for several months in the sky and observable mainly in X-ray, UV, and Optical wavebands. These are also efficient probes to study the SMBHs in the inactive galaxies. They study these

energetic transients by observing them in optical, UV, X-ray, and radio wavebands using ground and space-based telescopes to study their properties, and also uGMRT to perform low-luminous radio observations of jetted TDEs. Recently, they have also detected Bowen Fluorescence effect in TDE.

Modelling the energy dependent temporal behaviour of transient black hole binaries using *AstroSat*

Accreting black hole X-ray binaries (BHXBs) in outburst exhibit random short-term variability in their flux, which may arise due to the perturbations occurring at different radii of the accretion disk propagating inwards. These perturbations cause variations to mass accretion rate at the inner regions of accretion disk on different time-scales. The X-ray variability in BHXBs are well represented by their power density spectra (PDS), which exhibit systematic changes throughout the course of an outburst with remarkable similarities among themselves, thereby suggesting a common under lying physical phenomenon. The PDS of most BHXBs are characterized by broadband continuum noise like features and sometimes narrow peak features called quasi-periodic oscillations (QPOs). The exact mechanism of origin of QPOs is still an open question, but the origin of broadband noise could be due to the inward propagation and coupling of perturbations occurring throughout the accretion disk resulting in flux variations. This scenario best explains the observed linearity of the rms-flux relationship in galactic black holes, and other type of X-ray sources shows that the rms-flux relationship of broadband noise is an universal feature of all accreting BHXBs, independent of their spectral state. Sneha Prakash, **Bari Maqbool Bhat**, **Ranjeev Misra** and others presented the results of the first broadband simultaneous spectral and temporal studies of this newly detected black hole binary MAXI J1820+070 as seen by SXT and LAXPC on-board AstroSat. MAXI J1820+070, brightest X-ray source till date, was first detected in the optical on 6th March 2018, by the ASSAS-SN project and later in X-rays on 11th March 2018, by MAXI. Subsequent multi-wavelength observations of the source categorized it as a galactic black hole transient. The soft lags between the energy bands 0.11 keV and 110 keV was seen for the first time in a BHXB. The combined spectra from NuSTAR and SWIFT/XRT revealed the presence of a dominant thermal Comptonization and weak disk emission along with relativistic reflection fraction. Moreover, the spectral studies estimated the source inclination angle to be $\sim 30^o$ and the inner disk radius to be ~ 4.2 times the radius of the innermost stable circular orbit. The observed combined spectra in the energy range 0.7-80 keV were well modelled using disk blackbody emission, thermal Comptonization, and a reflection component. The spectral analysis revealed that the source was in its hard spectral state ($\Gamma = 1.61$) with a cool disk ($kT_{in} = 0.22$ keV). They reported the energy dependent time-lag and root mean squared (rms) variability at different frequencies in the energy range 3-80 keV using LAXPC data.

They also modelled the flux variability using a single zone stochastic propagation model to quantify the observed energy dependence of time-lag and fractional rms variability and then compared the results with that of Cygnus X-1. Additionally, They also confirmed the detection of a QPO with the centroid frequency at 47.7 mHz. (See Fig. 14).

Relativistic reflection fraction and photon index in AGN

The primary X-ray emission from Active Galactic Nuclei (AGN) is believed to be produced by the Comptonisation of the optical/UV photons from the accretion disc by the hot electrons in the corona. This primary power-law continuum irradiates the accretion disc and the circumnuclear material producing reflection features in the X-ray spectrum. Thus, the observed X-ray spectrum of AGN is a combination of the reflection spectrum and the primary power law. Since the reflection features are dependent on the structure, temperature, chemical composition and ionisation state of the gas, the reflection spectrum in AGN can give direct information about the physical conditions in the reflecting medium. Also, the area of the reflector and the location of the X-ray emitting region can affect the amount of reflection. Furthermore, the reflection features arising from the inner regions of the disc could be significantly modified by the relativistic effects near the black

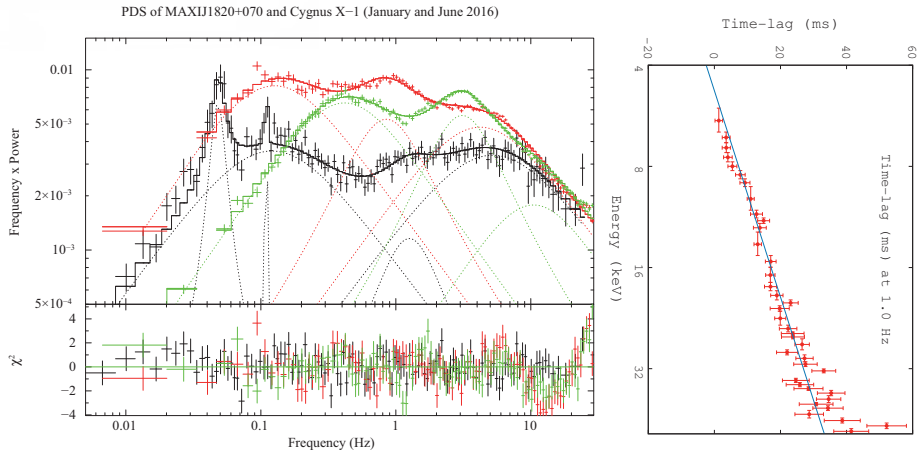


Figure 14: Comparative PDS of MAXI J1820+070 (Black colour) and Cygnus X-1 January (Green colour) and June (Red colour) 2016 in the 380 keV energy band. PDS of the source is fitted with five Lorentzian components of which the two narrow peaks represent a QPO at 47.7 mHz and a weak oscillation at 109.4 mHz respectively. PDS of Cygnus X-1 is fitted with 2 and 3 Lorentzian components for January and June respectively (Left Panel). The right panel shows the time-lag as a function of energy at 1 Hz for MAXI J1820+070. The time-lags are increasing with the increase in energy and have been fitted using the fluctuation propagation model.

hole. Hence, a study on the relativistic reflection fraction R_f, defined as the ratio of the coronal intensity that illuminates the accretion disc to the coronal intensity observed directly, can provide important information regarding the geometry of the accretion disc and the corona.

Here, **Savithri Ezhikode**, **Gulab C. Dewangan**, **Ranjeev Misra**, and Ninan Sajeeth Philip investigate the relationship between the relativistic reflection fraction R_f and the hard X-ray photon index Γ of a *NuSTAR* sample of Seyfert 1 galaxies. The X-ray spectra are modelled using RELXILL code which helps to directly obtain the reflection fraction of a relativistically smeared reflection component. The parameter R_f depends on the amount of Comptonised X-ray emission intercepted by the inner accretion disc. The parameter is found to range from ∼0.12(0.13) to ∼3.75(4.85) for different spin parameters ($a = 0(0.998)$). They found a strong positive correlation between Γ and R_f in our sample (See Fig. 15). As the slope of the X-ray power law is related to the rate of cooling of the plasma, steeper X-ray spectra indicate stronger cooling by the seed photons. The larger the area covered by the accretion disc as seen from the corona, the higher will be the seed photons entering the corona resulting in the steepening of the X-ray spectrum. Since the same accretion disc is responsible for the reflected emission, the larger area covered by the medium consequently enhances the reflection fraction. Thus, the observed $R_f - \Gamma$ correlation is most likely related to the variations in the disc-corona geometry of AGN.

Spectral and timing properties of the galactic X-ray transient Swift J1658.2-4242 using AstroSat observations

Black hole transients spend most of their lives in quiescence and are primarily discovered when they enter into outbursts characterized by abrupt changes in their X-ray luminosity by several orders of magnitudes. Swift J1658.2–4242 is a new Galactic X-ray transient source discovered by the BAT instrument onboard *Swift* on 2018 February 16 and extensively studied using different instruments in optical, radio and X-ray wavelength. **Vadakkumthani Jithesh**, **Bari Maqbool Bhat** and **Ranjeev Misra** studied the detailed X-ray timing and spectral analysis of Swift J1658.2–4242 using the LAXPC and SXT instruments onboard *AstroSat*. They detected prominent C-type quasi-periodic oscillations (QPOs) of frequencies varying from ∼ 1.5 Hz to ∼ 6.6 Hz along with distinct 2nd harmonics and sub-harmonics. The QPO detected at ∼ 1.56 Hz drifts to a higher

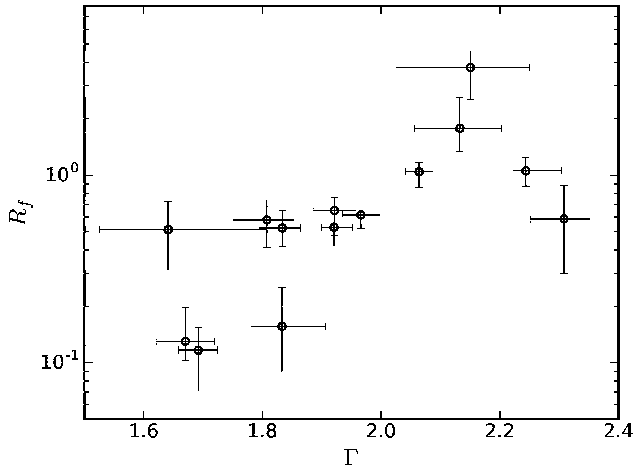


Figure 15: Relationship between R_f and Γ (for spin 0) for the *NuSTAR* sample Seyfert 1 galaxies.

centroid frequency of ~ 1.74 in the course of the observation, while the QPO detected at ~ 6.6 Hz disappeared during hard flarings. The fractional rms at the QPO and the sub-harmonic frequencies increases with photon energy, while at the 2nd harmonic frequencies, the rms seems to be constant. In addition, a soft time lag at QPO and sub-harmonic frequencies is observed up to a time scale of ~ 35 ms (see Fig. 16), however, at the 2nd harmonic frequencies, there is weak/zero time lag. The broadband X-ray spectral modelling in the 0.7–25 keV band using the doubly absorbed disk plus thermal Comptonization model identified the source to be in the hard intermediate state of black hole X-ray binaries. Using a single zone fluctuation propagation model, they quantified the frequency-dependent fractional rms and time lag. The energy-dependent temporal behaviour can be explained by the variation of the temperature of the corona and the disk with a time lag between them.

Broadband X-ray spectral study of ultra-luminous X-ray source M81 X–6

Ultraluminous X-ray sources (ULXs) are a class of extragalactic, compact, non-nuclear X-ray sources with X-ray luminosities in the range of $10^{39} - 10^{41}$ erg s^{-1}. **Vadakkumthani Jithesh**, C. Anjana and **Ranjeev Misra** investigated the temporal and broadband X-ray spectral properties of the ULX M81 X–6 using simultaneous *Suzaku* and *NuSTAR* observations. To understand the nature of the source, they first searched for pulsating signals from the source using the *NuSTAR* observation. However, the temporal analysis did not identify any strong pulsating signals from the source. Alternatively, the broadband spectral modelling with accreting magnetic neutron star continuum model provides a statistically acceptable fit for the broadband X-ray spectrum, and the inferred spectral parameters and X-ray colours are consistent with other pulsating ULXs. Thus, the spectral analysis suggests that M81 X–6 is another candidate ULX pulsar.

A compact X-ray emitting binary and 4FGL J0935.3+0901

4FGL J0935.3+0901 is a γ-ray source detected by the Large Area Telescope (LAT) onboard the *Fermi Gamma-Ray Space Telescope*. **Vadakkumthani Jithesh** and collaborators have conducted detailed analysis of the LAT data for this source and multi-wavelength studies of the source field. Its γ-ray emission can be described with a power law ($\Gamma = 2.0 \pm 0.2$) with an exponential cutoff ($E_c = 2.9 \pm 1.6$ GeV), while the flux shows significant long-term variations. From analysis of archival *Neil Gehrels Swift* X-ray Telescope data, they find only one X-ray source in the LAT's 2σ error region. Within a 3.7 arcsec radius error circle of the X-ray source, there is only one optical object down to $r' \sim 23$ mag. Time-resolved photometry of the optical object indicates a likely 2.5 hr

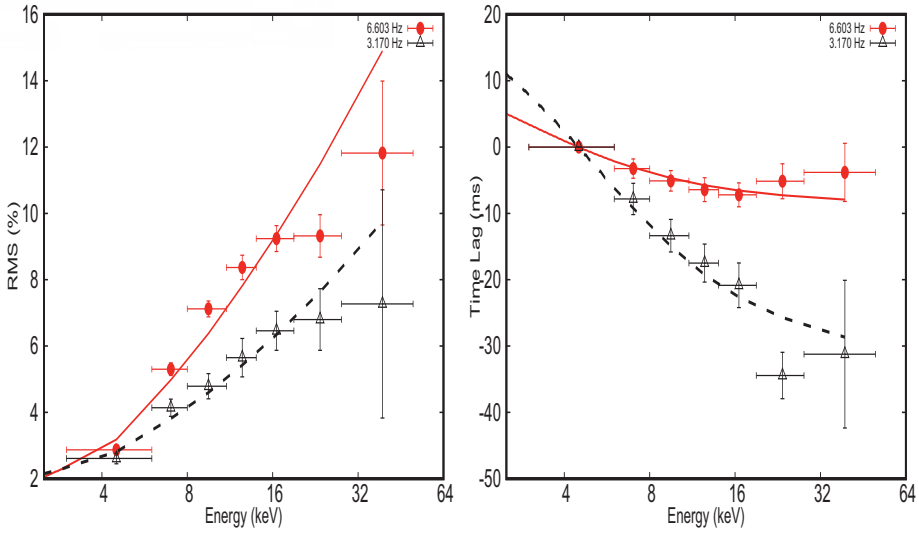


Figure 16: Fractional rms (left) and time lag (right) as a function of photon energy from the low intensity level data of AstroSat observation conducted during March 3 - 4, 2018. The red filled circle and black open triangle represent the QPO frequency at $\sim$ 6.60 Hz and the sub-harmonic at $\sim$ 3.17 Hz, respectively. The red solid line and black dotted line represent the model fit derived from the fluctuation propagation model for the QPO and the sub-harmonic, respectively.

periodic modulation, while its spectrum shows double-peaked hydrogen and helium emission lines (similar to those seen in accretion discs in low-mass X-ray binaries). These properties suggest that 4FGL J0935.3+0901 is a compact X-ray emitting binary belongs to the millisecond pulsar (MSP) class. Detailed optical spectroscopic analysis indicates that this binary could be a transitional MSP system at a sub-luminous disc state, although the other possibility, the binary in a rotation-powered state showing the optical emission lines due to intrabinary interaction processes, can not be excluded.

Puzzling blue dips in the black hole candidate Swift J1357.2-0933, from ULTRACAM, SALT, ATCA, Swift, and NuSTAR

A few years ago, a low-mass black hole in our galaxy was discovered to show strange dips in its optical light. Not corresponding to any stars or planet orbiting it, and appearing to be fairly regular for such a normally chaotic system, these dips meant that the system itself presented something of an enigma. Called Swift J1357.2-0933 (or J1357), this has led it to being a subject of much study, to try and discover the underlying processes.

By observing in optical light (ULTRACAM/NTT, Chile; and SALT, South Africa), X-rays (Swift and NuSTAR, Low Earth Orbit) and radio (ATCA), **John A. Paice**, Poshak Gandhi, **Ranjeev Misra** and collaborators found that the dips were not only present once again - four years after their discovery - but J1357 was found to be much bluer during them than outside of them. Additionally, superimposing many of the dips together, it was also confirmed that there is no dip in the X-rays at the same time as that in the optical (see Fig. 17). When also considering behaviour of each band with respect to one another, it was postulated that the black hole could (amongst other features) host a recessed disc, as well as a red-coloured jet base that is sporadically occulted by outer material.

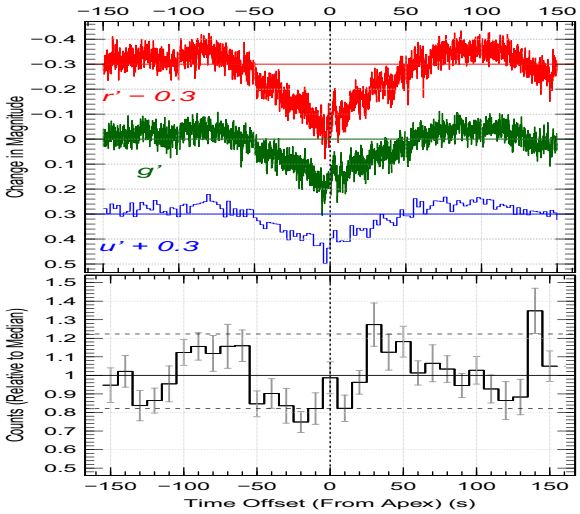


Figure 17: The top panel shows the superposition of twelve dips in the optical, in three bands - r (red), g (green) and u (blue). Note that how the blue light dips much less than the red. Also on average, the dips have a V-shaped profile, reminiscent of partially-eclipsing systems. The bottom panel shows the average X-ray response - the dashed horizontal lines show the 5-95% significance lines. Further, how the lightcurve rarely strays out of this region across the optical dip, confirming a lack of X-ray response.

A black hole X-ray binary at $\sim$ 100 Hz: Multiwavelength timing of MAXI J1820+070 with HiPERCAM and NICER

In 2018, a new black hole was discovered in our galaxy, briefly flaring to become the brightest X-ray source in the sky after the Sun. Capitalising on the opportunity, **John A. Paice**, Poshak Gandhi, **Ranjeev Misra** and collaborators studied the source (known as MAXI J1820+070, or J1820) in both optical (HiPERCAM/GTC, La Palma) and X-ray (NICER, ISS) light at over 300 frames per second. What they saw was a complex source that emitted red-coloured flares over a broad range of timescales, down to 10ms long. By looking at how the two wavelengths related to each other, it was found that while the two bands were mostly anti-correlated (a rise in X-rays would lead to a decline in optical), there was also a correlated optical lag at roughly 170ms (so an X-ray flare would lead to an optical flare after that delay).

Such behaviour, it is being found, is fairly normal for black holes - but close analysis of the optical lag found it differ, increasing with wavelength; so, following an X-ray flare, blue light would flare before green, and both would flare before red, at a time difference just visible to the telescope (see Fig. 18). Such a result has never been seen before; the authors have postulated that it could be the result of waves of plasma colliding within a jet, with higher-energy blue and green light being emitted closer to the black hole itself, before the lower-energy red light is emitted further away. If so, this could be the next step in understanding jet physics, and the phenomena around these enigmatic and violent sources.

Determination of log-normal flux distributions for astrophysical systems

Determining whether the flux distribution of an astrophysical source is a Gaussian or a log-normal, provides key insight into the nature of its variability. For example, the light curve produced by an additive sequence of many independent emission components results in a normal distribution of flux. However, if the underlying physical process produces random emission components in a multiplicative sequence, then resulting time series distribution would be log-normal. **Zahir Shah**, **Ranjeev Misra** and Atreyee Sinha carried extensive simulations of lightcurves with different lengths, vari-

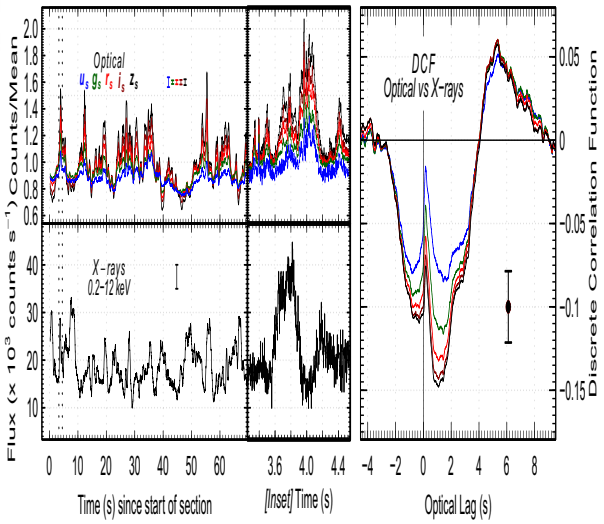


Figure 18: The left panel shows the optical (top) and X-ray (bottom) lightcurves, with intense flaring seen in every band, with optical activity stronger at longer, red wavelengths. The inset shows a zoom-in of a single second (∼300 frames), where an optical flare follows one in X-rays by ∼ 170ms. The right panel shows the correlation function between the optical bands and X-rays - here, a broad anti-correlation at ∼ second timescales, as well as the optical delay of ∼170ms can be seen - this latter feature is apparently common in black hole binaries, and could relate to a jet.

ability, Gaussian measurement errors and power spectrum index β (i.e., $P(f) \propto f^{-\beta}$), and provided guidelines for reliable use of skewness and Anderson-Darling (AD) tests. They provided empirical fits to the standard deviations of the skewness and tabulated critical values for the AD test for $\beta =$ 0.5 and 1.0, which differ from the values given in literature for white noise. The skewness standard deviation and critical values can be used to determine significance by which the tests reject that the distribution is normal. More importantly, they have addressed a conceptually paradoxical issue regarding non-Gaussian flux distributions. While Gaussian distributions remain Gaussian on addition (binning), this in general is not true for other distributions such as a log-normal one. Thus, it is not clear why several astrophysical systems display log-normal distributions when the lightcurves they are estimated from, are always binned to some time-bin? They resolve this issue by showing that if the power spectra of the lightcurves can be described by a power law with index $\beta \gtrsim 0.5$, then the nature of the distribution is invariant to binning. Thus, for a system to be scale free in time and have a log-normal flux distribution its power spectra must be steeper than 0.5. This insight may have important consequences for the model development and understanding of systems with log-normal distributions.

Study of long-term flux and photon index distributions of blazars using RXTE observations

Blazars are an extreme class of active galactic nuclei (AGN) with powerful relativistic jets of plasma pointing close to the line of sight of the observer. Rukaiya Khatoon, **Zahir Shah**, **Ranjeev Misra** and Rupjyoti Gogoi carried a detailed study of flux and index distributions of three blazars [one flat-spectrum radio quasar (FSRQ), and two BL Lacertae objects (BL Lacs)] by using 16 years of Rossi X-ray Timing Explorer (RXTE) archival data. The blazars were selected such that their flux and index distributions have sufficient number of data points (≥ 90) with relatively less uncertainty ($\overline{\sigma_{err}^2}/\sigma^2 < 0.2$). Using the AD test and histogram fitting, they showed that flux distribution of FSRQ 3C 273 is lognormal, while its photon index distribution is Gaussian. They interpreted the result interms of linear Gaussian perturbation in the particle acceleration time-scale, which

produces lognormal distribution in flux. However, for two BL Lacs, viz., Mrk 501 and Mrk 421, AD test shows that their flux distributions are neither Gaussian nor lognormal, and their index distributions are non-Gaussian. The histogram fitting of Mrk 501 and Mrk 421 suggests that their flux distributions are more likely to be a bimodal, and their index distributions are double Gaussian. Since, Gaussian distribution of index produces a lognormal distribution in flux, double Gaussian distribution of index in Mrk 501 and Mrk 421 indicates that their flux distributions are probably double lognormal. Observation of double lognormal flux distribution with double Gaussian distribution in index reaffirms two flux states hypothesis. Further, the difference observed in the flux distribution of FSRQ (3C 273) and BL Lacs (Mrk 501 and Mrk 421) at X-rays suggests that the low-energy emitting electrons have a single lognormal flux distribution, while the high-energy ones have a double lognormal flux distribution.

The long-term X-ray flux distibution of Cygnus X-1 using RXTE-ASM and MAXI observations

Cygnus X-1 is one of the brightest galactic black hole binary systems in the sky. Generally, the X-ray emission of Cygnus X-1 falls into one of the two distinct states, viz. "low-Hard" and "high-Soft". Kabita Deka, **Zahir Shah, Ranjeev Misra** and Gazi Ameen Ahmed carried a detailed X-ray flux distribution study of Cygnus X-1 using the RXTE-ASM and MAXI long-term B and C band light curves. They characterized the X-ray flux distribution of Cygnus X-1 by constructing the normalized histograms of B-band and C-band light curves such that each bin in the histogram has equal number of flux points. Since the long-term X-ray emission of Cygnus X-1 is predominantly in Hard-state and Soft-state, they fitted the flux histograms of B and C bands simultaneously with the double probability density function (PDF). The reduced-χ^2 obtained from different double PDF shows that the lognormal+Gaussian PDF provides a better fit to the RXTE B and C band histograms, while double-lognormal PDF results in better fit to the MAXI B and C-band histograms. Also, histogram fitting shows that the Hard-state flux distribution in both RXTE and MAXI observations is lognormal, while the Soft-state has the Gaussian distribution in case of RXTE observation and lognormal distribution for the MAXI observation. Moreover, they also checked the tri-model fit of the histograms, as Cygnus X-1 sometimes is also found in the intermediate state. However, the fitting did not improve upon using three component PDF, suggesting that the intermediatory spectral class may not correspond to a distinct component of the flux distribution. Moreover, the histogram fitting together with spectral state definition of *Grinberg V., et al., 2013*, suggests that the intermediate state is not a separate state, rather it is a extreme extension of Soft-sate.

Stars, Interstellar Medium and Planetary Studies

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

High-resolution optical spectra were obtained by **Ranjan Gupta**, during the period 2017-2019 using the Southern African Large Telescope (SALT) for 15 stars in the direction (lines of sight) of the Vela supernova remnant. These observations are on the interstellar CaII H and K and NaI D lines, and are discussed in details in our recent publication (Rao, et al., MNRAS, **493** 497, 2020). In particular, the line profiles are compared with profiles at a comparable spectral resolution obtained in the period 1993 - 1996 by Cha and Sembach (2000). Ten of the sight-lines show changes to one or more of the components in those respective line of sights. Changes include small (1-2 kms^{-1}) in radial velocity and/or increases/decreases in the equivalent widths over the two decades between the periods of observation. Changes are more obvious in the Ca K lines than in the NaD lines and are attributed to gas disturbed by interactions between the supernova ejecta and the surrounding interstellar medium. A representative time-scale may be 20-50 years. Small-scale variations in line profiles across the face of the remnant suggest, as previously remarked, that a linear scale for interactions is a small fraction of the 40 pc size of the present remnant. Figs. 19 and 20 are samples

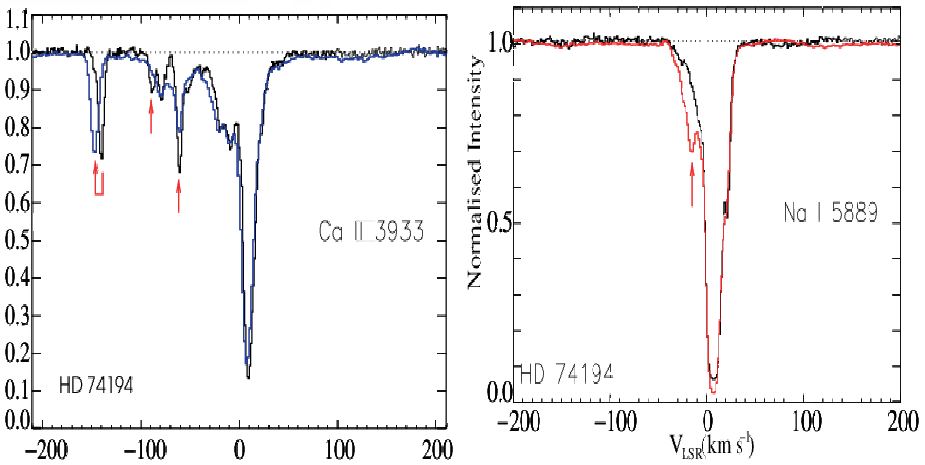


Figure 19: (Left): The profile of the CaII K line in HD 74194 obtained during 1993 (black line) by Cha and Sembach is superposed on the profile obtained on 2019 May 17 with the SALT (blue line). (Right): Profile of NaI D2 line in HD 74194 obtained in 1996 by Cha and Sembach (black line) shown superposed on the profile of NaI D2 line observed on 2019 May 17 with the SALT (red line). The red arrows indicate the changes to the components between Cha and Sembachs and SALT observations

of line profile changes which are seen along the sight-lines of HD74194 and HD72350.

Compact stars and the nuclear equation of state

Neutron stars are among the densest objects in the Universe. Under the extreme densities present in their core, strangeness-carrying particles (such as hyperons, kaons or deconfined quark matter) could appear. The presence of such "exotic" matter could influence neutron star phenomena, and their understanding is crucial for the correct interpretation of astrophysical observables. Multi-messenger observations (gravitational wave, multi-wavelength electromagnetic) from mergers of neutron stars provide us with information rich in physics under such extreme conditions. The stability of the merger remnant depends crucially on the underlying nuclear equation of state (EoS) and thus, provides a method to probe the nature of dense matter. Since the detection of GWs from the NS binary merger event GW170817, the fate of the binary remnant remains a mystery. As no evidence of a remnant has yet been found from post-merger searches by the LIGO-VIRGO collaboration, one may study different possibilities theoretically. One likely outcome of the merger is a metastable differentially rotating hot hypermassive neutron star. As the stability (dynamical and secular) and time of subsequent collapse of the remnant depend on its interior composition, it opens the possibility to constrain the dense matter EoS from its stability analysis.

In a recent publication, **Debarati Chatterjee** and her collaborators Sarmistha Banik and Krishna Prakash Nunna, searched for possible signatures of strangeness in the neutron star interior on the secular stability of the merger remnant. They calculated the onset of secular instability for different realistic (phenomenological) EoSs with and without strangeness using the Turning Point criterion, and investigated the maximum mass that may be supported by differential rotation and thermal effects. They found that inclusion of thermal effects reduced the maximum mass of the differentially rotating configurations. This is interesting as the hypermassive remnant is conjectured to be hot, and hence, thermal effects cannot be neglected. This was the first realistic study of the secular stability of neutron star merger remnants that used consistent hot and cold EoSs of dense matter. Using realistic EoSs including hyperonic and kaonic degrees of freedom, they also found that the maximum supported mass obtained depends both on the EoS and the degree of differential rotation.

They further investigated the effect of strangeness on the collapse time of the merger remnant. They considered the scenario in which the hypermassive NS merger remnant rapidly loses angular

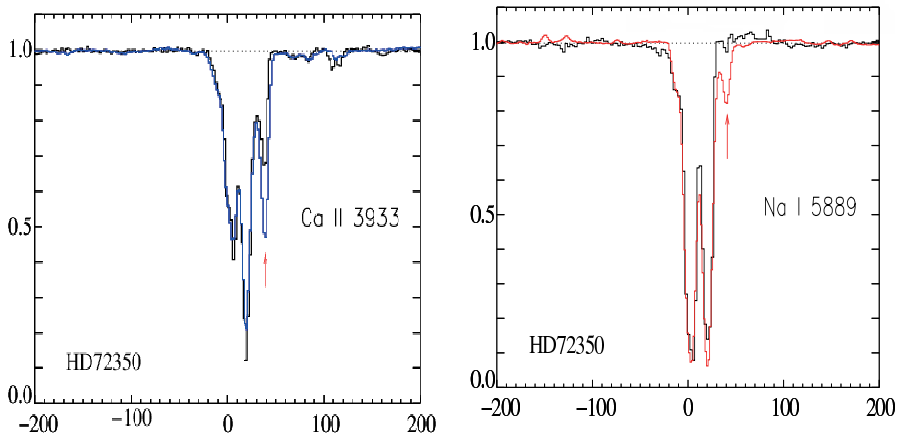


Figure 20: (Left): The profiles of CaII in HD 72350 obtained during 1996 (black line) by Cha and Sembach are superposed with the profile obtained on 2018 February 3 with the SALT (blue line). (Right): Profile of NaI D2 in HD 72350 obtained by Cha and Sembach (black line) is shown superposed on the profile of NaI D2 observed on 2018 February 3 with the SALT (red line). Note the strengthening of the +39 kms^{-1} component in both CaII and NaI

momentum due to loss of energy by GW emission and collapses to a black hole before the Alfven timescale, i.e., before the differential rotation is damped by magnetic dissipation. This scenario is currently favoured by the combined multi-messenger astrophysical observations. They estimated the collapse time and threshold mass for prompt collapse for the EoSs with and without strangeness, using recently proposed fit formulas obtained using observations of short gamma ray bursts and hydrodynamical simulations.

Solar Astrophysics

Doppler shift and its centre-to-limb variation in active regions in the transition region

This work is based on combined observations of the Interface Region Imaging Spectrograph (IRIS) and the Atmospheric Imaging Assembly (AIA) and the Helioseismic and Magnetic Imager (HMI), both on-board the Solar Dynamic Observatory (SDO). It is aimed at understanding the role of Doppler motions in transferring mass and energy in an active region in the lower transition region of the solar atmosphere. This incorporates a detailed study of the role of line-of-sight (LOS) magnetic fields in this dynamic coupling, with observations of the same bipolar active region 12641 as it moved across the disk from east to west. (See Fig.21).

Using the LoS magnetic field observations from HMI and Siiv 1394 Angstrom line emission recorded by IRIS, **Durgesh Tripathi** and collaborators infer that the two opposite polarity strong field regions, separated by a narrow weak field corridor, are predominantly redshifted to 5-10 km/s. On the contrary, the weak field corridor has redshifts ranging between 3-9 km/s. Both velocity estimates depend on the disk position. However, a common feature for all disk positions is a narrow lane within the corridor region with near-zero velocities. Therefore, the Doppler velocities in the corridor has two components- a low velocity component centered near 0 km/s and a comparatively higher velocity component at around 10 km/s. This component and the velocities in the strong fields show a small CLV within an error margin of $\pm$0.23-2.00 km/s. Moreover, these are independent of the systematic errors (0.87 km/s) incurred in the measurements. To explain the observations, we suggest that the emission in the lower transition region comes from "Type II spicules". They, further, invoke the idea of a "chromospheric wall", associated with classical cold spicules, so as to explain the small CLVs of flows.

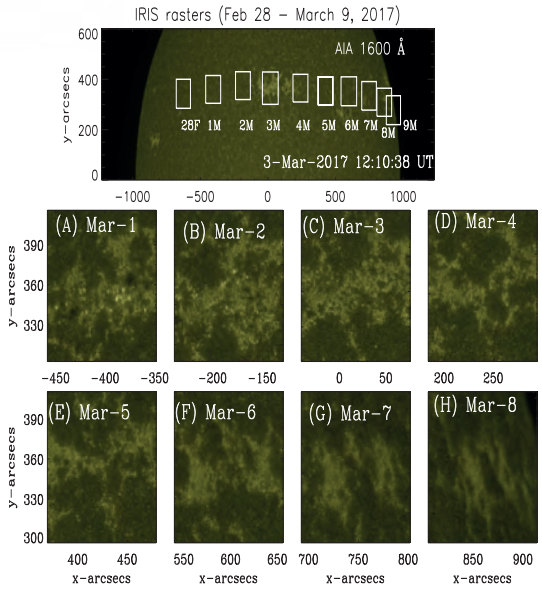


Figure 21: Top panel: AIA 1600 Angstrom channel image in the background on March 3, 2017 showing AR 12641. The over-plotted white boxes show the IRIS raster FoV between February ('F') 28 to March ('M') 9, 2017. Middle and bottom panels: Zoomed-in views of the IRIS raster FoV between March 1 and 8 as observed by AIA 1600 Angstrom channel.

Formation of sunspots and space weather

Two important goals of solar physics are to understand the solar dynamo mechanism that is responsible for the cyclic global magnetic activity of the Sun, and to be able to make an early prediction of energetic events, such as coronal mass ejections and solar flares, which have direct impact on terrestrial life. These phenomena are powered by magnetic fields generated within the Sun. The sunspot formation mechanism is the missing part of the overall distributed turbulent dynamo paradigm of the solar magnetism, as in most studies the sunspot-like magnetic concentrations do not form in a self-consistent manner. This is remedied to some extent in the ongoing numerical work by **Nishant Singh** and his collaborators as they now have the first hints of spot-like structures appearing spontaneously on the surface.

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(b) PROCEEDINGS

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(c) CIRCULARS AND TELEGRAMES

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25. **Manojendu Choudhury, Jayashree Roy, Yash D. Bhargav, Dipankar Bhattacharya,** A. R. Rao (2019) *Astrosat Observation of Cygnus X-3 in the Flaring State*, Astronomers' Telegram No. 12741.

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27. **Ramkrishna R. Gaikwad, Vidushi Sharma, Dipankar Bhattacharya, Ajay M. Vibhute**, Varun Bhalerao, et al. (2019) *GRB 190901A: AstroSat CZTI detection*, GCN Circular No. 25687.

28. **Ramkrishna R. Gaikwad, Vidushi Sharma, Dipankar Bhattacharya,** Varun Bhalerao, A. R. Rao, et al. (2019*) GRB 190828C: AstroSat CZTI detection*, GCN Circular No. 25745.

29. **Ramkrishna R. Gaikwad, Vidushi Sharma, Dipankar Bhattacharya, Ajay M. Vibhute**, Varun Bhalerao, et al. (2019) *GRB 190828B: AstroSat CZTI detection*, GCN Circular No. 25771.

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31. **Ramkrishna R. Gaikwad, Vidushi Sharma, Dipankar Bhattacharya,** V**arun** Bhalerao, A. R. Rao, et al. (2019) *GRB 190928A: AstroSat CZTI detection*, GCN Circular No. 25965.

32. **Ramkrishna R. Gaikwad, Vidushi Sharma, Dipankar Bhattacharya,** Varun Bhalerao, A. R. Rao, et al. (2019*) GRB 191009A: AstroSat CZTI detection*, GCN Circular No. 26004.

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34. **Ramkrishna R. Gaikwad, Shivom Gupta, Vidushi Sharma, Dipankar Bhattacharya, Ajay M. Vibhute**, et al. (2019) *GRB 191026B: AstroSat CZTI detection*, GCN Circular No. 26077.

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38. **Ramkrishna R. Gaikwad, Shivom Gupta, Vidushi Sharma, Dipankar Bhattacharya,** Varun Bhalerao, et al. (2019) *GRB 191129A: AstroSat CZTI detection*, GCN Circular No. 26316.

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41. **Ramkrishna R. Gaikwad, Shivom Gupta, Vidushi Sharma, Ajay M. Vibhute, Dipankar**

Bhattacharya, et al. (2019) *GRB 191218A: AstroSat CZTI detection*, GCN Circular No. 26482.

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80. **Vadakkumthani Jitesh, Bari Maqbool Bhat, Gulab C. Dewangan,** and **Ranjeev Misra** (2019) *Large flares from GRS 1915+105 in its unusual low state as observed by AstroSat*, Astronomer's Telegram No. 12805.

81. Rukaiya Khatoon, **Vadakkumthani Jithesh**, … **Zahir Shah, Ranjeev Misra,** and Rupjyoti Gogoi (2019) *Swift follow up of the renewed flaring phase of blazar SBS 1150 + 497*, Astronomer' Telegram No. 13285.

82. **Tanazza Khanam, Vidushi Sharma, Dipankar Bhattacharya, Ajay M. Vibhute,** Varun Bhalerao, et al. (2019) *GRB 190411A: AstroSat CZTI detection*, GCN Circular No. 24118.

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89. **Vidushi Sharma, Dipankar Bhattacharya, Ajay M. Vibhute, Tanazza Khanam,** Varun Bhalerao, et al. (2019) *GRB 190407B: AstroSat CZTI detection.,* GCN Circular No. 24121.

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(d) BOOKS

Ajit K. Kembhavi, and Pushpa Khare

- *Guruttviy Tarang –Vishwdardshnache Nave Sadhan* (in Marathi) (Gravitational Waves –A New Tool to

Watch and Understand Universe), Rajhans Prakashan, Pune (2019).

Jayant V. Narlikar

- *Samagra Jayant Narlikar: Kadambari* (in Marathi) (Collection of novels by Jayant Narlikar), Rajhans Prakashan Pvt. Ltd., Pune (2020).

T. Padmanabhan, and Vasanthi Padmanabhan

- Dawn of Science - Glimpses from History for the Curious Mind, Springer (2019).

(e) POPULAR ARTICLES

Jayant V. Narlikar

- *Are we aliens?*, Down to Earth, 53 (2019).
- *Excellence in higher education: The Mahamana' vision*, Souvenir, International Alumni Meet (2020).
- *Bachpan ki kuch yaadein* (in Hindi) (A few childhood memoirs), Pitrudevo Bhava, 20 (2019).
- *Vaidnyanik drustikon* (in Marathi) (Scientific outlook), Manashakti, Diwali Issue, 12 (2019).
- *Vidnyan aani guptapolice* (in Marathi) (Science and detectives), NRIPOJAGAT, 15 (2019).
- *Prakash pradushan: Avakash nirikshanatil adthala* (in Marathi) (Light pollution: An obstacle to space observations), Vanarai, 8 (2019).
- *Time machinechi kimaya* (in Marathi) (The miracle of time machine), Kishor, 12 (2019).
- *IUCAAcha shree ganesha* (in Marathi) (The starting of IUCAA), Jesthaparva, Diwali Issue, 59 (2019).

PEDAGOGICAL

(a) IUCAA –NCRA Graduate School

Dipankar Bhattacharya

Methods of Mathematical Physics I (21 lectures) (August –September 2019).

Sukanta Bose

Quantum and Statistical Mechanics II (14 lectures) (October –December 2019).

Gulab C. Dewangan

Astronomical Techniques I (14 lectures) (January –February 2020).

Neeraj Gupta

Astronomical Techniques II (14 lectures) (March –May2019).

Ranjeev Misra

Electrodynamics and Radiative Processes II (14 lectures) (October –December 2019).

Surhud More

Galaxies: Structure, Dynamics and Evolution (21 lecture) (January –February 2020).

T. Padmanabhan

Methods of Mathematical Physics II (21 lectures) (October –December 2019).

Aseem Paranjape

Research Methodology (Statistics Module) (7 lectures) (January 2020).

Varun Sahni

Extragalactic Astronomy I (21 lectures) (January –February 2020).

Raghunathan Srianand

Interstellar Medium (14 lectures) (March –May 2020).

Kandaswamy Subramanian

Quantum and Statistical Mechanics I (21 lectures) (August –September 2019).

(b) SAVITRIBAI PHULE PUNE UNIVERSITY MSc LECTURES (Departments of Physics, and Department of Space Science)

Aseem Paranjape

Astronomy and Astrophysics II (General Relativity and Cosmology) (18 lectures) (January - April 2020, but interrupted in March 2020 due to Covid-19 outbreak).

Ranjan Gupta

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

(c) SUPERVISION OF PhD THESES (Degrees Awarded)

Sukanta Bose

Title: *Gravitational Waves from Compact Binaries as Probes of Neutron Star Equation of State and Extra Spatial Dimension.*
Student: Kabir Chakravarti (IUCAA)

Title: *Strategies for Searches of Electromagnetic Counterparts of Gravitational Wave Signals.*
Student: Javed Rana Sk. (IUCAA)

Tarun Souradeep

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

Aseem Paranjape

Title: *Aspects of Semi-Classical Limit and the Backreaction Problem.*
Student: Rajeev Karthik (IUCAA)

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

(d) SUPERVISION OF PhD THESES (Ongoing)

Dipankar Bhattacharya

Title: *Accretion-Induced Evolution of Neutron Star Magnetic Field.*
Student: Suman Bala (IUCAA)

Title: *Spectro-Timing Study of Accretion Disks.*
Student: Yash Bhargava (IUCAA)

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

Title: *Indirect Imaging in Astronomy.*
Student: Ajay M. Vibhute (IUCAA)

Title: *An Investigation of Polarised Emission from Accreting Binary X-ray Pulsars.*
Student: Parisee Sunil Shirke(IUCAA)

Sukanta Bose

Title: *Constraining the Equation of State of Neutron Stars with Gravitational Wave Observations.*
Student: Bhaskar Biswas (IUCAA)

Title: *Improved Methods for Discriminating Gravitational Wave Signals of Compact Binary Coalescences from Noise Transients.*
Student: Sunil Choudhary (IUCAA)

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

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

Title: *The Physics and Astrophysics of Binary Black Hole Mergers and their Gravitational Radiation.*
Student: Vaishak Prasad (IUCAA)

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

Title: *Characterizing the Properties and Constitution of Compact Objects in Gravitational-Wave Binaries.*
Student: Samanwaya Mukherjee (IUCAA)

Gulab C. Dewangan

Title: *Multi-Wavelength Observations of Accretion Disks in Active Galactic Nuclei.*
Student: Pranoti Y. Panchbhai (IUCAA)

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

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

Sanjit Mitra

Title: *Algorithms for Gravitational Waves Data Analysis and Detector Controls Based on Modern Techniques.*
Student: Sreejit P. Jadhav (IUCAA)

Title: *Science Potentials of a Space-based Deci-Hertz Gravitational Wave Observatory.*
Student: Piyali Ganguly (IUCAA)

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

Student: Deepali Agarwal (IUCAA)

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

Surhud More

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

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

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

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

Aseem Paranjape

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

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

A. N. Ramaprakash

Title: *Alternative Techniques for Adaptive Optics for Future Large Telescopes.*
Student: Sorabh Chhabra (IUCAA)

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

Somak Raychaudhury

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

Varun Sahni

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

Tarun Souradeep

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

Title: *Precision Physics from CMB Polarisation Anisotropies.*

Student: Rajorshi S. Chandra (IUCAA)

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

Raghunathan Srianand

Title: *Probing the Astrophysical and Cosmological Aspects of Intergalactic Medium using Quasar Spectra.*
Student: Soumak Maitra (IUCAA)

Title: *Probing Environment of High Redshift Quasars using Diffuse Lyman-αEmission.*
Student: Gitika P. Shukla (IUCAA)

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

Title*: Probing the ultra-fast outflows in BAL quasars using multi-epoch spectroscopy.*
Student: Aromal P (IUCAA)

Durgesh Tripathi

Title**:** *Energetics of the Solar Atmosphere.*
Student: Abhishek Rajhans (IUCAA)

(e) SUPERVISION OF PROJECTS

Dipankar Bhattacharya

Tanushree Chowdhury (Sri Venkateswara College, New Delhi) *Equation of State and the Structure of Compact Stars.*

Anwesha Maharana (IISER, Pune) *Structure and Stability of Magnetically Confined Mounds on Neutron Stars.*

Avinash Manoj Sontakke (BITS,Pilani) *Earth' Gravity.*

Debarati Chatterjee

Sukrit Jaiwal (IISER, Pune) *Internal Composition on Neutron Star Oscillation Modes; and Study of Correlations between Nuclear and Astrophysical Observables.*

Savithri H. Ezhikode

Hafiz Nazeer (University of Calicut, Kozhikode) *A Study of the X-ray Variability in the AGN Mrk~110*.

Sariga C.M. (Providence College, Kozhikode) *X-ray Studies of AGN with AstroSat.*

Vadakkumthani Jithesh

Zainul Abid P. (University of Calicut, Kozhikode) *Broadband X-ray Spectral Variability of Black Hole X-ray Binary MAXI J1820+070.*

Divyarani C. G. (NIT,Surathkal) (Vacation Students'Programme, IUCAA) *Search for the Transient Supersoft X-ray Sources in the Nearby Galaxies*.

Jobin Mathew Jose, and Ramshad V. R. (St. Thomas College, Ranni) *Spectro-Timing Analysis of the New Black Hole Binary Candidate Swift J1658.2-4242.*

Annmaria J. Puthur (Vimala College, Trissur) *Searching the Optical and UV Counterparts of Candidates MSPs.*

Sister Lydia Sertho (Vimala College, Trissur) *Spectral Study of ULX NGC 55 ULX1 Using Swift Observations.*

Sreelakshmi T. (Providence Women's College, Kozhikode) *Timing Studies of GRS 1915+105 in its Unusual Low State using AstroSat LAXPC.*

Shivaraj Kandhasamy

Ishan Joshi (Fergusson College, Pune) *Reducing Environmental Coupling using Wiener Filtering.*

Anupreeta More

Saloni Deepak (University of Delhi) *Determining the Host Luminosity for a Gravitationally Lensed AGN.*

Suprio Dubey (BITS –Pilani, Ranchi) *Determination of the Mass Profile of a Galaxy Cluster using Various Mass Probes.*

Chatrik Singh Mangat (Hyderabad) *Cosmological Constraints using a Double Source Plane Lens System.*

Anushka Menon (Fergusson College, Pune) *Identifying Lensed Supernovae Ia from Multi-Band Imaging Data.*

Surhud More

Bhavana Bhat (Fergusson College, Pune) *Cosmic Shear Measurements in Weak Lensing Surveys.*

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

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

Aseem Paranjape

Raghav Arora (BITS-Pilani, Goa)(Vacation Students' Programme, IUCAA) *Group-finding Algorithms for Cosmological Large Scale Structure*.

Nikhil Bisht (BITS-Pilani, Goa*) Lagrangian Perturbation Theory.*

PayaswineeDhoke (M. P. Deo Memorial College, Nagpur) *Environmental Effects on Dark Matter Haloes in Warm Dark Matter Cosmologies* (Ongoing).

ShreejayaKaranth (Indian Academies Summer Student) *Special and General Relativity*.

Rupak Roy

Kaustav Chatterjee (IISER, Mohali) *Superluminous Supernovae.*
Kiran Jayasurya (IIST, Thiruvananthapuram) *Spectroscopic Modelling of Tidal Disruption Events*(Co-supervision).

Haqnawaz Rafiq (University of Kashmir, Srinagar) *Spectroscopic Study of the Nuclear-Transients.*

Akriti Singh (IIST, Thiruvananthapuram) *Understanding the Nuclear-Transient*(Co-supervision).

Varun Sahni

Apoorva Shah (Fergusson College, Pune) *Dark Energy and the Accelerating Universe.*

(f) SEMINARS, COLLOQUIA, AND LECTURES

Bari Maqbool Bhat

Modelling the Timing Properties of the Black Hole Binary CYG X-1, 14th Asia-Pacific Physics Conference, Borneo Convention Centre Kuching, Sarawak Malaysia, November 17, 2019.

Dipankar Bhattacharya

Introduction to Pulsars, International Pulsar Timing Array, Student Week, NCRA, Pune, June 10, 2019.

Results on Compact Objects from AstroSat, International Conference on the Future of X-ray Timing, Amsterdam, The Netherlands, October 23, 2019.

(i) *Introduction to Astronomy and Astrophysics,* (ii) *Tools of Astronomy: Telescopes and Detectors*, (iii) *Stars*, and (iv) *Galaxies, Dark Matter and the Universe*, IUCAA–IAPT Workshop on Physics in Action, December 20–22, 2019.

Debarati Chatterjee

Neutron Stars as Gravitational Wave Sources, IUCAA, March 5, 2020.

Savithri H. Ezhikode

X-ray Astronomy for PG Students and Teachers, St. Thomas College, Ranni, during February 1–2, 2020.

Introduction to Active Galactic Nuclei (Talk), and *X-ray Data Analysis* (Hands-on Session), St. Thomas College, Ranni, February 1 - 2, 2020.

Gulab C. Dewangan

UV/X-ray Emission from Seyferts, International Meeting on Recent Progress in Relativistic Astrophysics, Fudan University, China, May 6–8, 2019.

SXT Calibration Status and UV/X-ray Spectroscopy with AstroSat, 14th IACHEC Meeting, Shonan Village Centre, Japan, May 20–23, 2019.

AstroSatand UV/X-ray Emission from Active Galactic Nuclei, Tokyo Institute of Technology, May 24, 2019.

Interplay between the Accretion Disk and Corona in Active Galactic Nuclei, NCRA –TIFR, Pune, November 11, 2019.
AstroSat UV/X-ray Connection in Accreting Objects, School of Physics and Astronomy, University of Southampton, November 22, 2019.

AstroSatand UV/X-ray Observations, International Workshop on Astronomical X-Ray Optics, Prague, Czeck Republic, December 2 –6, 2019.

Observational Probes of AGN Central Engines, Discussion Meeting SMBH2019, ICTS, Bebgakuru, December 17 –19, 2019.

Sanjeev V. Dhurandhar

Gravitational Waves: From Discovery to Astronomy, Saha Institute of Nuclear Physics, Kolkata. June 4, 2019; IISER, Kolkata, June 6, 2019; and Gujarat Science Congress, Ganpat University, Mehsana, February 9, 2020 (Plenary talk).

(i) *Early Days of Gravitational Wave Research in India,*and (ii) *Data Analysis of Gravitational Waves*, Meeting on Future of Gravitational Wave Astronomy, ICTS, Bengaluru, August 20 –21, 2019.

A Unified Approach to Chi Square Discriminators: Gravitational Waves from Compact Binary Coalescences, Institute of Cosmic Ray Research, Tokyo University, Kashiwa Campus, Japan. October 11, 2019.

The Enigma of Gravitation: From Newton to Einstein and Beyond, Frontiers in Physics, Fergusson College, Pune, February 17, 2020.

Neeraj Gupta

The MeerKAT Absorption Line Survey, Galaxy Evolution in a New Era of HI Surveys, MIAPP, Munich, July 29, 2019.

Large Survey with SALT: Radio Bright Quasars for the MeerKAT Absorption Line Survey, SALT Science Meeting, IUCAA, November 13, 2019.

Ranjan Gupta

Spectrographs and Spectra: Observation and Data-Reduction Techniques, 5th Indo –French Astronomy School on Spectroscopy and Spectrographs, IUCAA, August 16 –24, 2019.

Modelling of Mid-InfraRed Polarization in Dust around Young Stars, International Conference on Infrared Astronomy and Astrophysical Dust (IRAAD), IUCAA, October 22 –25, 2019.

Time Variability of Interstellar Lines in the Direction of the Vela Supernova Remnant, SALT Science Meeting, IUCAA, November 13 –14, 2019.

India' Involvement in Mega Projects in Astronomy, LCOGT, Santa Barbara, CA, USA, December 20, 2019.

Dust and Polarimetry, Space Application Centre, Ahmedabad, January 13, 2020.

Vadakkuthani Jithesh

Long-Term Spectral Variability and Searching the Pulsating Nature of ULX M81 X—, Kuching, Malaysia, 14th APPC, November 17 –22, 2019.
Overview of X-ray Astronomy and X-ray Binaries, Seminar on X-ray Astronomy, St. Thomas College, Ranni, Kerala, February 1 –2, 2020.

Shivaraj Kandhasamy

Update on O3 Radiometer Analyses, LIGO-VIRGO-KAGRA Collaboration Meeting, Warsaw, Poland, September 2, 2019; and March 17, 2020 (Online).

Data Quality and Calibration of LIGO-Virgo Detectors, The Newton-Bhabha and the Open Data Workshop, IUCAA, December 5, 2019.

Anupreeta More

Strong Gravitational Lensing, Refresher Course in Astronomy and Astrophysics (for College/University Teachers)/Vacation Students'Programme, IUCAA, May 31,2019.

ML Applications to GW Data: CBC Search and Analysis, Workshop on Applications of Data Science in Astrophysics and Gravitational Wave Research, IIIT, Allahabad, November 2,2019.

Surhud More

Cosmological Constraints from the Subaru Hyper Suprime-Cam Survey, Ruth Marshak Lecture, American Physical Society, Denver, Colorado, April 15, 2019.

Lectures on Cosmology, Astronomy Olympiad, HBCSE, Mumbai, May 6, 2019.

Cosmology from Electromagnetic Observations, ICTS, Bengaluru, August 20, 2019.

(i) *Cosmological Constraints from Weak Lensing Surveys*, and (ii) *The Hunt for Planet Nine*, IISER, Mohali, September 4 –5, 2019.

Cosmological Constraints from Weak Lensing Surveys, 38th Meeting of the Astronomical Society of India, IISER, Tirupati, February 15, 2020.

Ranjeev Misra

Radiative Processes in Astrophysics, Workshop on Astronomical Data Analysis, J. B. College, Jorhat, September 2019.

AstroSat: A New Era for Rapid X-ray Timing, Introductory Workshop on Physical Perspectives of Astronomy, ICFAI, Tripura, October 2019; Workshop for AstroSat Data analysis, Goa University, November 2019;and St. Thomas College, Ranni, February 2020.

AstroSat: Spectro-Temporal Analysis of X-ray Binaries, Transient Astronomy, ISRO, Bengaluru, November 2019.

Jayant V. Narlikar

How Well Do we Know our Universe?, ICTS, Bengaluru, August 19, 2019.

Some Conceptual Problems in Cosmology, GLA University, Mathura, October 11, 2019.
A Glimpse into Astrobiology, Advanced Centre for Treatment, Research and Education in Cancer, Navi Mumbai, December 5, 2019.

T. Padmanabhan

Gravity and the Cosmos, M.P. Birla Memorial Award Lecture, Kolkatta, September 29, 2019.

(i) *Emergent Gravity Paradigm: Concepts and Overview*, and (ii) *Emergent Gravity Paradigm: Highlights and Open Issues*, Workshop on Emergent Gravity Paradigm, CUSAT, Kochi, November 8 –10, 2019.

Thermality of Horizons, Distinguished Lecture Series, Department of Physics, IIT –Bombay, Mumbai, January 27, 2020.

Avatars of Gravity, IIT, Gandhinagar, February 27, 2020.

Aseem Paranjape

Assembly Bias and Tidal Fields, Dynamics of LSS Formation Meeting, MIAPP, Munich, Germany, July 14 - 27, 2019.

Sujata Ramakrishnan

*Cosmic Web Anisotropy is the Primary Indicator of Assembly Bias,*Dynamics of LSS Formation Meeting, MIAPP, Munich, Germany, July 14 –27, 2019.

Karthik Rajeev

Cosmic Web Anisotropy is the Primary Indicator of Assembly Bias, YAM –2019, Kodaikanal Solar Observatory, September 23 –27, 2019.

Exploring the de Sitter Spacetime, Workshop on Emergent Gravity Paradigm, CUSAT, Kochi, November 2019.

Kanak Saha

Far and Near-Ultra Violet Deep Imaging Survey of the Chandra Deep Field South and Beyond, Extragalactic Deep Fields, European Week of Astronomy and Space Science, Lyon, France, June 24, 2019.

An Overview of Indian Astronomy, European Week of Astronomy and Space Science, Lyon, France, June 27, 2019 (Plenary talk).

Astronomical Facilities in India and AstroSat/UVIT Observation, Group Seminar, Geneva Observatory, Switzerland, July 1, 2019.

Exploring the UV Deep Field by AstroSat, Tezpur University, Assam, September 12, 2019; and Israel –ASH and INSA Workshop on Astrophysics and Planetary Science,December 3, 2019.

AstroSat and its UV Capability, BRICS Astronomy Working Group and Workshop, Brazil, September 30, 2019.

Exploring Galaxy Formation using AstroSat, Gorakhpur University, November 21, 2019; and LBS College, Gonda, November 22, 2019.
Exploring the Early Galaxy Formation by AstroSat, Diamond Harbour Women' University,Sarisha, West Bengal, January 31, 2020.

Galaxy Kinematics in the Era of IFU, 38th Meeting of the Astronomical Society of India, IISER, Tirupati, February 13, 2020.

Zahir A. Shah

Flux Distribution Study of Fermi Bright Blazars and Simulated Light Curves, Astronomy Group Seminar Programme, University of Southampton, United Kingdom, October 14, 2019.

Nishant K. Singh

*Basics of Magnetohydrodynamics and Space Weather,*Workshop on Science of the Star in our Backyard: Introduction and Data Analysis, St. Mary College, Wayanad, December 26 –29, 2019.

Durgesh Tripathi

Dynamics of the Sun' Atmosphere, Department of Physics, BHU, Varanasi, April 18, 2019.

Doppler and Non-Thermal Motions in Transition Region of Active Regions, 9th Coronal Loops Workshop, St Andrews University, Scotland, June 11 –14, 2019.

Space Weather and Sun Climate with Aditya –L1, Towards Future Research on Space Weather Drivers, San Juan, Argentina, July 2 –7, 2019.

Challenges in Solar Astronomy, 5th North –East Meet of Astronomers, Tezpur University, September 11 –13, 2019.

Formation of Hot Plasma in the Core of an Active Region, 10th IRIS Workshop, Bengaluru, November 4 –8, 2019.

The Aditya –L1: A Space Based Solar Observatory of Indian Space Research Organisation, 10th IRIS Workshop, Bengaluru, November 4–8, 2019.

Testing the Flare Localization Algorithm for Solar Ultraviolet Imaging Telescope (SUIT), *using IRIS and AIA data,* 10th IRIS Workshop, Bengaluru, November 4–8, 2019.

Our Life-Giving Star: The Sun, Variable Energy Cyclotron Centre, Kolkata, November 29, 2019.

(i) *Solar Ultraviolet Imaging Telescope on Aditya –L1,*(ii) *Amplitude Modulation of MHD Waves Observed in Fan Loop*, (iii) *Evolution and Plasma Diagnostics in the X-region of TELs*, (iv) *Solar Wind Prediction using Deep Learning,*and (v) *Hydrodynamics of Transient BrighteningsObserved by Hi-C,* 5th AsiaPacifi Solar Physics Meeting, IUCAA, February 3 –7, 2020.

The Solar Ultraviolet Imaging Telescope on Board Aditya-L1 Mission, Queens University Belfast, UK. February 25, 2020; and Armagh Observatory, UK, February 26, 2020.

The Science Goal of SUIT Payload, First Aditya Science Meeting, ISRO Headquarter, Bengaluru, March 6 –7, 2020.

Multi-Payload QS Science using Aditya-L1, First Aditya Science Meeting, ISRO Headquarter, Bengaluru, March 6 –7, 2020.

(g) LECTURE COURSES

Dipankar Bhattacharya

Introduction to Astronomy and Astrophysics and Radiative Processes (4 lectures), Refresher Course in Astronomy and Astrophysics (for College/ University Teachers)/ Vacation Students'Programme, IUCAA, May 13 –14, 2019.

Physics of Compact Objects, (3 lectures), ARPIT Online Course on Astronomy and Astrophysics, Recording Studio, IISER, Pune, July 30 –31, 2019.

Computational Methods in Astronomy (11 lectures), Topical Course, IUCAA, January –March 2020.

Gulab C. Dewangan

X-ray Astronomy and Active Galactic Nuclei (2 lectures), Refresher Course in Astronomy and Astrophysics (for College/University Teachers)/Vacation Students'Programme, IUCAA, May –June 2019.

Sanjeev V. Dhurandhar

Gravitational Waves: An Overview (2 lectures),Refresher Course in Astronomy and Astrophysics (for College/University Teachers)/Vacation Students'Programme, IUCAA, Pune, May 24, 2019.

Statistics of Gravitational Wave Detection (3 lectures), Workshop on Applications of Statistics in Astrophysics, Assam University,Silchar, November 20 –22, 2019.

General Relativity and Gravitational Waves (3 lectures),SRTM University, Nanded, January 15 –16, 2020.

Ranjan Gupta

Basics of Astronomy (4 lectures), Advance Meteorological Training Course (Batch 180), Naval Officers and IMD Recruits, IMD –CTI, Pune, January 27 –28, 2020.

Dipanjan Mukherjee

Computational Methods in Astrophysics (7 Lectures), Topical Course, IUCAA, January - May 2020.

Jayant V. Narlikar

Cosmology (8 lectures), Centre for Excellence in Basic Sciences, Mumbai, April 7 –17, 2019.

T. Padmanabhan

The Interface between QT and GR (10 lectures), Topical Course, June 2019.

Horizon Thermality, QFT and Gravity (3 lectures),IISER, Mohali, September 24 –26, 2019.

Aseem Paranjape

Special Relativity and the Principle of Equivalence (3 lectures), IUCAA-IAPT Under-graduateProgramme, BITS-Pilani, Goa, December 2019.

Kanak Saha

Galaxy Dynamics (3 Lectures), Refresher Course in Astronomy and Astrophysics (for College/University Teachers)/Vacation Students'Programme,IUCAA, June 10 –11, 2019.

Highlights of Extragalactic Research (2 lectures),5th Indo-French Astronomy School on Spectroscopy and Spectrographs,IUCAA, August 21, 2019.

Nishant K. Singh

Computational Methods in Astronomy (2 lectures), Topical Course, IUCAA, 2020.

Durgesh Tripathi

Stars: Structure and Evolution (3 lectures),Refresher Course in Astronomy and Astrophysics (for College/University Teachers)/Vacation Students' Programme, IUCAA, June 2 –3, 2019.

Challenges in Solar Astronomy (2 lectures), Exploring the Universe, ICARD Activity, Gorakhpur, November 21 –22, 2019.

(h) POPULAR/ PUBLIC LECTURES

Tek Prasad Adhikari

Black Holes and Active Galactic Nuclei, Pokhara Astronomical Society, Pokhara, Nepal, April 30, 2020 (online).

Debarati Chatterjee

Gravitational Waves: Exploring the Invisible Universe, Women in Space Sector, Darmstadt Space Raumfahrt Fans, Darmstadt, Germany, January 7, 2020.

Gulab C. Dewangan

X-ray Vision in Astronomy, Philips India, Pune, November 6, 2019.

Sanjeev V. Dhurandhar

Einstein's Legacy: The Discovery of Gravitational Waves, Marathi Vidnyan Parishad, Goa Vibhag, Madhgaon, Goa, August 10, 2019.

The Discovery of Gravitational Waves and Beyond: Parts Iand II, Khalsa College, Delhi University, North Campus, September 25, and 27, 2019.

The Discovery of Gravitational Waves, Students Science Club, Kothrud, Pune, November 24, 2019.

The Enigma of Gravitation: From Newton to Einstein and Beyond, National Centre for Cell Sciences, Pune, January 10, 2020.

Neeraj Gupta

(i) *Science with the Square Kilometre Array: HI Perspective,*and (ii) *Square Kilometre Array: The Largest Radio Telescope,*Vigyan Samagam, Nehru Science Centre, Mumbai, June 22, 2019.

Anupreeta More

Gravitational Lensing Discoveries at your Fingertips, Marathi Vidnyan Parishad, Ambernath, May 5, 2019.

Unravelling the Dark Side of the Universe with Gravitational Lensing, CCOEW, Pune, November 16,2019.

Surhud More

Chandrayaan II, India's Mission to the Moon, B.D. Kale College, Landewadi, Ambegaon, October 3, 2019.

Search for Planet Nine, Marathi Vidnyan Parishad, Ambernath, May 5,2019.

Jayant V. Narlikar

Logical Thinking, Department of Physics, University of Mumbai, April 10, 2019.

The Importance of Logical Thinking, MIT Academy of Engineering, Pune, April 30, 2019; and Infosys, Pune, May 8, 2019.

Convocation Address, IISER, Bhopal, May 31, 2019.

Why Study Astronomy?, 2nd Saturday Lecture/ Demonstration Programme, IUCAA, Pune, July 13, 2019; Gandhi Centre for Science and Human Values, Jawaharlal Nehru Planetarium, Bengaluru, August 17, 2019; and Readers of ' Juger Kishor Vigyani' Institute of Culture, Kolkata, September 27, 2019.

Khagolshastra ka shikave? (in Marathi) (Why Study Astronomy?), 2nd Saturday Lecture/ Demonstration Programme, IUCAA, Pune, January 5, 2019; Arts, Commerce and Science College, Arvi, Dist. Wardha, January 5, 2020; and Marathi Vidnyan Parishad, Pune Vibhag, Pimpri Chinchwad Science Park Auditorium, Pune, March 1, 2020.

The Culture of Science, Jawaharlal Nehru Planetarium, Bengaluru, August 18, 2019.

Gurutvakarshanachya laharin cha shodh (in Marathi) (Search for Gravitational Waves), Jalgaon Zilla Shaskiya Abhiyanta Sahakari Patpedhi Maryadit, Jalgaon, September 16, 2019.

Are we Alone in the Universe?, GLA University, Mathura, October 12, 2019.

Amazing World of Astronomy, Jamia Millia Islamia, New Delhi, October 14, 2019.

Gravitational Waves: Their Nature, Emission and Detection, Muktangan Exploratory Science Centre, Pune,

December 11, 2019.

Satyen Bose ek preranadayi vaidnyanik (in Marathi) *(Satyen Bose: An Inspiring Scientist)*, Nehru Centre, Mumbai, December 14, 2019.

Gurutvakarshanachya lahari (in Marathi) (Gravitational Waves), Swami Ramanand Teerth Marathwada University, Nanded, December 15, 2019.

The Creation of Centres of Excellence, Foundation Day Lecture of the Centre for Excellence in Well Logging Technology, Vadodara, February 2, 2020.

T. Padmanabhan

From Sun, Moon, and Stars to Calendar, Chandigarh Science Centre - Tagore Theatre,September 27, 2019.

(I) RADIO/TV PROGRAMMES

Debarati Chatterjee

Astro_Roamer, Podcast Channel to Popularize Physics/Astrophysics, https://soundcloud.com/user-171349851.

Sanjeev V. Dhurandhar

Gravity and the Cosmos, Varanasi Radio (Interview), May 15, 2019.

Anupreeta More

Interview on Khule Aakash, Aajchya kalatale shashtreeya Shodh (Series), All India Radio, Akashwani, Mumbai, February 6 –7, 2020.

Surhud More

Marathi television appearance on ABP Majha during the launch of Chandrayaan II, July 22, 2019.

Marathi television appearance on ABP Majha during the descent of Chandrayaan II's Vikram Lander on the Moon, September 6/7, 2019.

Jayant V. Narlikar

Interview on Sunitatai Deshpande, All India Radio, Pune, July 15, 2019.

Interview, All India Radio, Nagpur, January 3, 2020.

SCIENTIFIC MEETINGS AND OTHER EVENTS

Refresher Course in Astronomy and Astrophysics



The Refresher Course in Astronomy and Astrophysics for College and University Teachers was held at IUCAA, during May 13 - June 14, 2019. There were 24 participants, who came from different parts of India. The faculty coordinators for the Refresher Course were Aseem Paranjape and Surhud More. (For details, see KHAGOL No. 119 July 2019)

Vacation Students' Programme

The annual Vacation Students' Programme (VSP) was held during May 13 - June 28, 2019 at IUCAA. There were 14 students from various colleges/ universities/ institutes. Gulab C. Dewangan was the faculty coordinator of this programme. (For details, see KHAGOL No. 119 July 2019)





National Conference on Recent Trends in the Study of Compact Objects: Theory and Observation

IUCAA organized the fourth National Conference on Recent Trends in the Study of Compact Objects: Theory and Observation (RETCO) during April 17 - 20, 2019. The conference brought together researchers from all over India to discuss the recent theoretical and observational progress made in understanding the physics of accreting compact objects with special emphasis on the results from the AstroSat mission. Gulab C. Dewangan was the coordinator of the conference.

(For details, see KHAGOL No. 119 July 2019)

Indo - French Astronomy School (IFAS5) on Spectroscopy and Spectrographs

The IFAS5 (5th Indo-French Astronomy School) was held at IUCAA during August 16-24, 2019. This series of IFAS which are alternatively held at IUCAA, Pune and Lyon, France. The school coordinators were Philippe Prugniel from France and Kanak Saha and Ranjan Gupta from IUCAA. (For details, see KHAGOL No. 120 October 2019).



ASTRONOMY CENTRE FOR EDUCATORS



Inauguration of the Building

A significant event during this year has been the inauguration of the Teaching Learning Centre (TLC) building by K. VijayRaghavan, Principal Scientific Adviser to the Government of India on December 29, 2019.

(For details, see KHAGOL No. 121 January 2020)

Annual Refresher Programme In Teaching (ARPIT) 2019

The National Resource Centre (NRC) for Astronomy and Astrophysics hosted by IUCAA has developed an online course titled `Stars and Stellar Systems' for ARPIT 2019-20. The ACE staff involved in making this online course are Prakash Arumugasamy, Manojendu Choudhury, Sushan Konar, and Dhruba J. Saikia (Coordinator), with Aniket Kadu and Shivraj Kshatriya as video editors. The videos were filmed at the Science Media Centre of IISER, Pune. These videos are presently available via the Swayam platform.

(For details, see KHAGOL No. 120 October 2019)

Thirty-First Foundation Day Lecture

The 31st IUCAA Foundation Day Lecture was delivered on 29 December 2019 by K. VijayRaghavan, FRS, Principal Scientific Adviser to the Government of India. An alumnus of IIT Kanpur and TIFR, Mumbai, He is a distinguished professor in the field of developmental biology, genetics and neurogenetics.

(For details, see KHAGOL No. 121 January 2020)





International Conference on Infrared Astronomy and Astrophysical Dust (IRAAD - 2019)

The IRAAD - 2019 was held at IUCAA during October 22-25, 2019, and was attended by about 15 foreign participants from Japan, France, Russia, USA, and Canada, and 70 participants from India, and they were mainly PhD Students, Post-doctoral Fellows, and Faculty from Indian Institutes (IUCAA, IIA, TIFR, ARIES, SNBSC, ICSP, PRL, IIIST, etc.), and several Indian Universities (Gorakhpur, Assam, Tezpur, Mahatma Gandhi, Baroda, etc). There were 14 review talks, 27 contributory talks, and 28 posters. The posters summary was reported by Jan Cami and Els Peeters, and the overall conference summary was made by Eric Herbst. Ranjan Gupta (IUCAA), and Shantanu Rastogi (Gorakhpur University) were the coordinators of this conference.

(For details, see KHAGOL No. 121 January 2020)



Newton - Bhabha: Open Data (Indo – UK) Workshop

The joint Indo - UK Newton - Bhabha: Open Data Workshop was held at IUCAA during December 4-6, 2019. The main goal was to provide an opportunity for students, post docs and other academics interested in gravitational waves, and who would look forward to do science with the LIGO-India Observatory. There were 60 participants.

(For details, see KHAGOL No. 121 January 2020)



Radio Astronomy Winter School



The twelfth edition of the Radio Astronomy Winter School (RAWS) was conducted by the TLC of IUCAA along with the National Centre for Radio Astrophysics (NCRA), Pune, during December 16 - 24, 2019.

(For details, see KHAGOL No. 121 January 2020)



Second Indo-Chile Astronomy Dialogue

The 2nd Indo-Chile Astronomy Dialogue was organized at IUCAA, during December 3 – 5, 2019.There were 30 participants, attended in person, and through Skype. The dialogue was coordinated at IUCAA by Ranjan Gupta. (For details, see KHAGOL No. 121 January 2020)



5th Asia Pacific Solar Physics Meeting

The 5th Asia Pacific Solar Physics Meeting was hosted at IUCAA during February 3 - 7, 2020. The meeting was jointly organised by IUCAA and the Indian Institute for Science Education and Research (IISER), Pune. The meeting was co-sponsored by the Centre for Excellence in Space Science India (CESSI), IISER-Kolkata; Indian Institute of Astrophysics (IIA), Bengaluru; Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital; Indian Institute of Science (IISc), Bengaluru; and the Indian Space Research Organization (ISRO), Bengaluru.

(For details, see KHAGOL No. 122 April 2020)

PUBLIC OUTREACH

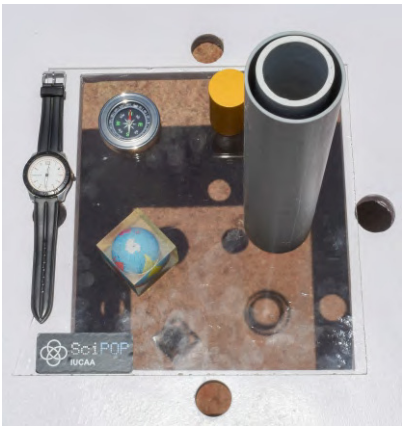


Global Astronomy Month

On the occasion of the Global Astronomy Month (GAM), April 2019, IUCAA SciPOP team organised themed public sky-gazing events on April 11 and 18, 2019. The event was coordinated by Sonal Thorve.

(For details, see KHAGOL No. 119 January 2019)





Zero Shadow Day

On May 14, 2019, the Zero Shadow Day for Pune was celebrated in IUCAA. Along with the members of IUCAA, the students of the Summer School and Vacation Students' Programme, and college/ university teachers of Refresher Course enjoyed, and observed the shadows of themselves and objects around disappear beneath their feet.

(For details, see KHAGOL No. 119 January 2019)

School Students' Summer Programme and Astronomy Camp



The annual School Students' Summer Programme and Astronomy Camp was conducted during May 6 - 31, 2019, at IUCAA. Thirty two students of classes VIII, IX and X, from schools of Pune as well as from rural areas near IUCAA Girawali Observatory (IGO) were invited to this programme at Muktangan Vidnyan Shodhika, IUCAA.
(For details, see KHAGOL No. 119, July 2019)

Workshop on Basic Astronomy for Educators, at Agastya Foundation, Kuppam, Andhra Pradesh

During the two-week long training programme for educators at Agastya Foundation, Kuppam, Andhra Pradesh, a two day Workshop on Basic Astronomy was organised during May 10 - 11, 2019. About 50 educators in and around Mumbai were invited to participate in the programme. Sonal Thorve, Tushar Purohit, Rupesh Labade and Maharudra Mate were the resource persons.

(For details, see KHAGOL No. 119, July 2019)









Inclusive Astronomy Workshop, at Smt. Patashibai Lunkad Blind School, Bhosari, Pune



On April 26, 2019, a workshop on basic astronomy was conducted at Smt. Patashibai Lunkad Blind School, Bhosari, Pune. About 40 blind students from classes VI to VIII enjoyed learning about our solar system and the universe.

They could visualise the scales of the planet sizes using inclusive model of the solar system. Neha Deshpande and Sonal Thorve were the resource persons.

(For details, see KHAGOL No. 119 January 2019)

Sally Ride Earth KAM, at New English School, Tilak Road, Pune



Following the enthusiastic response from school students last year, the IUCAA SciPOP team participated in the Sally Ride Earth KAM (Earth Knowledge Acquired by Middle School Students), run by NASA this year too, during May 10 - 12, 2019. The programme was coordinated by Shivom Gupta.

(For details, see KHAGOL No. 119, July 2019)

Science Toys Workshops, at Ghodegaon, and at Vidnyan Ashram, Kothrud

A Science Toys Workshop for school students was held on May 6, 2019, at the New English School, Ghodegaon. Around 150 students enjoyed learning basics of science with simple toys and experiments. Rupesh Labade coordinated and conducted the workshop.

On May 21, 2019, a similar workshop, a session on telescopes and hands-on astronomy was organised at Vidnyan Ashram, Kothrud, Pune. This was conducted by Rupesh Labade and Tushar Purohit.

(For details, see KHAGOL No. 119, July 2019)

Lecture on Celestial Sphere and Sky Map Reading, at Muktangan Exploratory

As part of the summer camps organised by Muktangan Exploratoty, Pune, a lecture on Celestial Sphere and Sky Map Reading was delivered on May 21, 2019, by Samir Dhurde. About 50 school students attended and enjoyed the session.

(For details, see KHAGOL No. 119, July 2019)

Teachers Training for Rural Schools near IGO



A two day workshop for secondary school teachers from rural area in and around IUCAA Girawali Observatory was held during July 29 - 30, 2019. On the first day, there were demonstrations of science toys along with hands-on activities related to the topics: sound and light. This was followed by introduction to optics and telescopes with an evening skywatching session. On the second day, there were lectures on textbook astronomy, hands-on astronomy, and role plays. The workshop was coordinated by Rupesh Labade and Sonal Thorve.

(For details, see KHAGOL No. 120, October 2019)

Telescope Making Workshops

IUCAA SciPOP in collaboration with Latur Science Centre, conducted a telescope making workshop during April 15 - 18, 2019. Totally 195 small refracting telescopes were made by students of classes VI to XII under the guidance of Tushar Purohit, who was the resource person from IUCAA.

During April 27 - 28, 2019, a similar telescope assembly workshop was organised at Pandit Deendayal Petroleum University Astronomy Club, at Gandhinagar. The students assembled 15 reflecting telescopes.

During June 19 - 23, 2019, a telescope making workshop was organised at Kendriya Vidyalay, Bhopal, in collaboration with Vigyan Prasar. Twenty larger (5 inch) reflecting telescopes were made by school teachers.

(For details, see KHAGOL No. 119, July 2019)





Astronomy Lecture, at Jyotirvidya Parisanstha

As part of the summer astronomy camp organised by Jyotirvidya Parisanstha, Pune, a lecture on Multi-wavelength and Multi-messenger Astronomy was delivered by Samir Dhurde on May 3, 2019. On May 16, 2019 Shivom Gupta delivered a lecture on Exoplanets. Around 50 participants attended the camp.

(For details, see KHAGOL No. 119, July 2019)





TMT Outreach Week, at Vigyan Samagam, Mumbai - from June 03 to 09

The team of outreach personnel from IUCAA were representing the LIGO-India and the Thirty Meter Telescope (TMT) projects at the Vigyan Samagam Science Mega projects exhibition held at Mumbai during May 27 - June 9, 2019.

(For details, see KHAGOL No. 119, July 2019)

State Level Children's Science Congress

IUCAA SciPOP was invited to the 27th State Level Children's Science Congress held during December 6 – 7, 2019, at Samarth Institute, Belhe, Maharashtra. Rupesh Labade coordinated the event. About 3,000 students participated and enjoyed learning science with toys. It was followed by sky-watching in the evening. Around 350 people visited and experienced a delightful view of telescopic objects like Moon and Saturn. Tushar Purohit and SonalThorve were the resource persons.









Moon Landing Anniversary

On the occasion of the 50th anniversary of first human landing on the Moon, IUCAA SciPOP organised a special event for school students on July 20, 2019. About 60 students from low profit/under privileged schools visited IUCAA, and learnt about the Apollo missions, India's own Chandrayaan missions, and had fun with activities like crater making, a photograph with the picture of first human footstep on the moon.

(For details, see KHAGOL No. 120, October 2019)



Teachers' Training Programme, at Pimpri

IUCAA SciPOP personnel, with the help of Pimpri - Chinchwad Science Park, organised a teachers' training programme at Pimpri - Chinchwad Science Park, Pimpri, on August 29, 2019, for science teachers. Sixty teachers from different Zilla Parishad and Municipal Corporation schools participated enthusiastically in the training programme. Rupesh Labade and Sonal Thorve coordinated and conducted the training.

(For details, see KHAGOL No. 120, October 2019)



Teachers' Training Programme, at Satara

IUCAA SciPOP personnel, with the help of Rayat Shikshan Sanstha, Satara region, organised a teachers' training programme during August 26 - 27, 2019, at Satara for science teachers from Zilla Parishad schools. Sonal Thorve coordinated the programme. Rupesh Labade, Shivom Gupta and Maharudra Mate were the resource persons.

(For details, see KHAGOL No. 120, October 2019)

Rural Outreach Events

During July - September 2019, science toys demonstrations and workshops were conducted at different schools in different places, nearby IGO. These schools were at Kanhur-Mesai, Nirgudsar, Pargaon, and Manchar. Around 500 students from rural schools enjoyed learning science through toys. All the events were coordinated and conducted by Rupesh Labade.

On September 3, 2019 a special session was conducted at Annasaheb Awte College, Manchar. The topic was Unravelling Science through Experiments and Models. About 130 BSc students were present for this session. This session was arranged by the college under Rayat Inspire Scheme. Rupesh Labade coordinated and conducted the session.

IUCAA Rural Outreach team was invited to give a talk and demonstrations on Chandrayaan - 2 on September 7, 2019 at C.T. Bora College, Shirur. The talk included information about IUCAA Activities, Guidance on Careers in Astronomy, and Exchange of Ideas with the students about the Chandrayaan - 2 landing and future missions of India. About 200 students, teaching and non-teaching staff were present. Models designed and built by Jyotirvidya Parisanstha, Pune were used for demonstration purposes. Rupesh Labade coordinated the event with the help of Atharva Pathak.








Teaching with Science Toys





A full day science toys workshop for volunteers was held on August 22, 2019. All the volunteers were given material kits to make 10 toys. The topics: sound, optics, electricity, motion, force, work and energy were covered in the session. Demonstrations of 20 to 25 toys were given with a brief instruction on how to use these toys in teaching textbook science and even more. The selected toys were connected with the existing science curriculum of the classes 8, 9 and 10, which would be helpful for the teachers and the volunteers in the classroom. The workshop was coordinated by Shivani Pethe and Rupesh Labade.

(For details, see KHAGOL No. 120, October 2019)

LIGO India and TMT Outreach Week

The team of outreach personnel from IUCAA were representing the LIGO-India and the Thirty Meter Telescope (TMT) projects at the Vigyan Samagam Science Mega projects exhibition at Bengaluru. With guidance from project leaders, over the past few months, a set of ten posters, a collection of short films as well as some interactive and live demonstrations have been put together by them. These are now a part of a grand pavilion showcasing Mega projects having India in a major partnership. Many volunteers have also been trained to explain the posters and exhibits to all visitors.

The special Outreach Week of LIGO-India, during August 13 - 17, 2019, was coordinated by Vaibhav Savant with Ankit Bhandari and Rameshwar Bankar. The events included 5 talks for the general public and students by several scientists. Live/interactive demonstrations like Space Quest, Black Hole Pong, Stretch and Squash, LIGO-in-your-hands were arranged.

For celebrating the TMT Outreach Week, during September 17 - 21, 2019, Samir Dhurde (as coordinator), Shivani Pethe and Rupesh Labade performed a special themed play combined with science demonstrations. It highlighted the developments since the time of Galileo Galilei in a lucid and attractive manner via DIY optics experiments. Everyone in the audience, especially school students, delved into the wonderful world of light and its properties with Galileo himself joining them! (For details, see KHAGOL No. 120, October 2019)



PuLastya Science Festival 2019

To commemorate the birth centenary of Late Shri Pu. La. Deshpande, November 8, 2019, PuLastya Science Festival was organised during November 7 - 9, 2019. Around 1,500 people visited IUCAA on this occasion.

(For details, see KHAGOL No. 121, January 2020)





Teachers' Training for Observing Solar Eclipse



Grabbing the opportunity of the Annular Solar Eclipse on December 26, 2019, IUCAA SciPOP personnel arranged a special session on December 15, 2019, for teachers on how to observe the eclipse. Samir Dhurde (IUCAA) delivered a talk on the same topic. This was followed by a hands-on session by Geeta Mahashabde (Navnirmiti Learning Foundation, Pune).

(For details, see KHAGOL No. 121, January 2020)

Workshop on Basic Astronomy

The students and teachers of the Renaissance School, Mansa, Punjab, participated in a two-day Workshop on Basic Astronomy, conducted by IUCAA SciPOP personnel at Mansa, during October 17-18, 2019. It was the first such a workshop conducted in this place. The workshop comprised of interactive sessions, science toys demonstration, hands-on activities based on observational astronomy and space sciences. Thirty-two students and ten teachers participated in the workshop. They were delighted to observe Moon using a large telescope.

India International Science Festival

IUCAA participated in the India International Science Festival (IISF), held at the Biswa Bangla Convention Centre, Kolkata, during November 4 – 8, 2019. As a part of the IISF - 2019, public sky-watching sessions were organised. Tushar Purohit and Jameer Manur (both from IUCAA) were the resource persons. Around 4,000 people participated in the activity. On November 7, a talk on Setting-up Low Cost Science Laboratories was delivered by Shivani Pethe (IUCAA), with emphasis on the importance of such laboratories in each school, even for class 1 students. A guideline for all teachers to setup such labs in their schools was also provided. Around 450 teachers attended the talk.

INYAS Science Camp

Indian National Young Academy of Sciences, in collaboration with IUCAA and D. Y. Patil Education Society, Kolhapur, Maharashtra, organised the INYAS Science Camp for school students during November 22 – 23, 2019, at Kolhapur. Science toys demonstration, hands-on science, and hands-on astronomy were covered in the sessions. Sonal Thorve, Shivani Pethe, and Rupesh Labade (IUCAA) were the resource persons. Around 180 school students participated in the camp. Sonal Thorve coordinated the camp.

Jigyasa Science Exhibition

A science exhibition open for all was organised at IISER, Pune, during December 19 – 20, 2019, by the Agastya International Foundation in collaboration with IISER, Pune and IUCAA SciPOP. Rupesh Labade was the resource person, who coordinated the telescope making activity. There were 200 student participants, and round 2,000 people visited the exhibition.

Annular Solar Eclipse Viewing at Different Parts of India

On the occasion of the Annular Solar Eclipse, a camp was jointly organised during December 25 – 26, 2019, at Coimbatore, Tamil Nadu, by the Vigyan Prasar of the Government of India and Jyotirvidya Parisansth, Pune. The participants were 180 teachers from different parts of India. Rupesh Labade and Maharudra Mate volunteered in the camp. As a part of the IUCAA Workshop on Science of the Star in our Backyard, held at St. Mary's College, Sulthan Bathery, Kerala, IUCAA SciPOP organised the Annular Solar Eclipse viewing for the general public on December 26, 2019. Samir Dhurde and Sonal Thorve were the resource persons.

The eclipse was viewed using safe solar eclipse goggles. Observation session was followed by an interactive talk on the eclipses delivered by Samir Dhurde. Jameer Manur and team observed the Annular Solar Eclipse from Kasaragod, Kerala. The weather permitted the team to observe and capture annularity of the eclipse.

Telescope Making Workshops

IUCAA SciPOP in collaboration with Vigyan Prasar conducted two Telescope Making Workshops at Navodaya Vidyalayas, Kamrup, Assam, during October 30 - November 4, 2019, and at Kendriya Vidyalaya, Gomtinagar, Lucknow, Uttar Pradesh, during November 18 – 22, 2019. Tushar Purohit was the resource person in these workshops.

Teachers' Training

A two-day training for secondary school teachers from rural area in and around IUCAA Girawali Observatory was held during December 14-15, 2019. The session was followed by a visit to IUCAA Girawali Observatory, at which sky-watching session was arranged. The second day was focused on the Annular Solar Eclipse that was going to be on December 26, and was observable from India.

This included hands-on activities and role play sessions. The training was coordinated by Rupesh Labade.



Solar Eclipse

The Annular Solar Eclipse observation and its live streaming was viewed throughout the country on December 26, 2019. At IUCAA, there was an overwhelming response from general public during the interactive sessions conducted by Surhud More (IUCAA) and team. Due to the cloudy sky, they were shown live streaming of the eclipse from different parts of the world. The general public enjoyed the programme even when they could not get an actual glimpse of the eclipse. (For details, see KHAGOL No. 121, January 2020)

IAUS 358, Conference on Astronomy for Equity, Diversity and Inclusive

The conference consisted of intensive panel discussions and presentations regarding the climate of inclusion in astronomy, the advantages and efforts taken by astronomers globally to make astronomy diverse and inclusive.





Neha Deshpande (IUCAA) presented the efforts IUCAA SciPOP is taking in making astronomy inclusive. She was invited to chair a discussion session about the astronomy for equity.

Along with a lot of statistics and efforts to bring about a positive change in society by experts, Deshpande concurred that an open dialogue and acknowledgement of the diversity in abilities of people is perhaps the key to the climate of inclusivity.

Science Toys Demonstration

For the students of classes 6 to 10, a Science Toys Demonstration was conducted at TBM Finishing School LLP at Otur, Maharashtra, on October 26, 2019, by Rupesh Labade. Around 80 students enjoyed the demonstration.



Science Exhibition

A Science Exhibition for Ambegaon Taluka schools was organised at Girawali, Maharashtra, by the Zilla Parishad, during December 3 – 4, 2019. Fifty schools nearby IUCAA Girawali Observatory participated in the exhibition. IUCAA SciPOP was invited to present science toys and the telescope demonstrations. Rupesh Labade was the resource person. Around 1,900 students visited and enjoyed the exhibition.



Science Toys Demonstrations in Schools, Pune

From January to March, 2020, Rupesh Labade (IUCAA) organised and conducted science toys demonstrations at different schools in and around Pune. These include Novel Junior College, Chinchwad; Maharshi Karve Vidyalay, Pune; and Mahilashram High School, Pune. Around 300 students benefited from this activity.

(For details, see KHAGOL No. 122, April 2020)

Telescope Assembly Workshop

BITS - Pilani, Hyderabad organised a telescope assembly workshop during January 18 - 19, 2020. Tushar Purohit and Atharva Pathak were the resource persons from IUCAA.

Teachers Training, Silvassa

A training event for teachers from all the Government schools of the Union Territory of Dadra-Nagar Haveli was organised by the Office of Education, DNH on January 30, 2020. Sonal Thorve and Atharva Pathak were the resource persons from IUCAA.

Telescope Making Workshops

IUCAA SciPOP in collaboration with Vigyan Prasar, New Delhi, conducted a Telescope Making Workshop at Navodaya Vidyalayas, Hyderabad, during July 5 - 22, 2019.

Tushar Purohit was the resource person. Totally 41 large (5 inch) reflecting telescopes were made by school teachers and students.

Workshop on Annular Solar Eclipse

On the occasion of upcoming solar eclipse on December 26, 2019, that will be visible from most parts of India, a workshop was organised during September 27 - 28, 2019, by KPRIET, Coimbatore in association with Galilio Science Club and IUCAA SciPOP. During the workshop, a guest lecture on 'Solar Eclipse and How to Observe it Safely' was delivered by Sonal Thorve.

The activities involved: understanding Moon's phases and eclipses using role-play, understanding time-zones using role-play, making of a ball-mirror projector to observe the Sun safely. Observing the Sun using other projection methods was also demonstrated.



Other Regular Events

During April 2019 to March 2020 the Public Outreach team has conducted 11 science toys workshops, 6 basic astronomy workshop, 30 campus visits, and 3 sky-watch sessions with an approximate reach to about 2,250 people.



National Science Day Celebrations - 2020

Taking the advantage of the leap year 2020, IUCAA extended the celebration of the National Science Day during February 28 - 29. The two-day celebrations attracted numerous groups of students along with teachers, parents and 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.

Short talks on Cosmology, Gravitational Waves, Next Generation Radio Astronomy, and Understanding the Universe through Large Optical Telescopes were delivered by Swagat Mishra and Sujatha Ramakrishnan, Sayantani Bera, Pratik Dabhade and Ashish Mhaske, and Siddharth Maharana, respectively, which kept the audience rooted in the Chandrasekhar Auditorium during the morning session. These sessions were coordinated by Sujatha Ramakrishnan and Swagat Mishra.

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 February 01, 2020.

All the public talks and Ask a Scientist session were streamed live and are available at:
https://www.youtube.com/iucaascipop. A special walkthrough of the National Science Day at IUCAA was made by Ishan Shinde with the help of Shashank Tarphe.







IUCAA - NCRA GRADUATE SCHOOL

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PH.D. PROGRAMME

During the year of this report, five IUCAA Research Scholars namely: **Kabir Chakravarti** (Guide: Sukanta Bose), **Niladri Paul** (Guide: Aseem Paranjape), **Karthik Rajeev** (Guide: Aseem Paranjape), **Shabbir Isak Shaikh** (Guide: Tarun Souradeep), **Javed Rana Sk.** (Guide: Sukanta Bose) have defended their Ph.D. theses. Their Ph.D. degrees have been awarded by the Jawaharlal Nehru University, New Delhi. The synopses of their theses are given below :



Kabir Chakravarti

Improving the Observation Aspects of Neutron Star Binaries Through Better GW Modeling

In a series of events, Gravitational Waves (GWs) were discovered by LIGO first from Binary Black Holes (BBH), and thereafter along with VIRGO from Binary Neutron Stars (BNS). These discoveries have put Einstein's General Theory of Relativity (GTR) on a firmer footing and ushered in the era of GW astronomy. As the sensitivities of the detectors improve, we can hope to obtain more and more precise data of the GW signal itself. Such data provide at least a twofold advantage. On one hand, they can be fed into data analysis pipelines to yield accurate information about the source. On the other hand, the data can also be used to test GTR or constrain modified gravity theories.

The tidal Love number is a very crucial parameter when it comes to understanding the physics of NSs through the GWs their binaries emit. This number has been found to leave imprints in both the amplitude and the phasing of the GW signal which become appreciable from the late inspiral phase upto the merger. So far as the physics of the merger is concerned, the first and foremost, the Love number is an important observational window into the presently ill understood Equation of State of extremely high density (10^{15} g/cc) material which forms the composition of NSs. Additionally, Love numbers are also sensitive to any deviation (of the underlying theory) from the GTR. Any modification to the theory will automatically mean a change in the equations for computing the Love number, making the constraining of this number a hot test bed for alternate scenarios to 4d Einstein gravity. Further, from the perspective of data analysis, it is also imperative to have estimates of statistical and systematic errors associated with the estimation of the Love number.

The thesis presented here covers broad ground, involving phenomenology, data analysis and theory. To begin with, we try to understand systematic errors associated with the estimation of the Love number from GW observations. Any systematic error present in the estimation of the Love number interferes with the predictability of the Love number, thereby making such error analysis extremely important. We were one of the first to study the systematic errors in the Love number with two different families of tidal templates using numerical waveforms obtained from two independent numerical codes. Next, we investigated the GW waveforms from double NS binaries in the postmerger regime. Our aim in this work was to compute statistical errors on the radii

of NSs using postmerger waveforms alone. Once again, we were one of the first to perform this calculation using analytical fits to the postmerger waveforms from numerical relativity codes.

We then moved on to the theoretical aspects of the Love number. Specifically, we wanted to observe the effects in the GW signal had there been the presence of an extra spacelike dimension. As we know, the models of extra dimensions were invoked to solve the gauge hierarchy problem in gravity, and also in String Theory. We computed Love numbers in a simple extra dimension scenario, before moving on to observationally constraining an extra dimension parameter .

Yet another anticipated observational feature is the Quasi Normal Modes (QNM) of a BH - which are rapid oscillations of a remnant for some time following the process of a compact binary merger. The spectrum of the oscillations reveal distinct frequency peaks, which correspond to different modes of oscillation. Specifically, for a BH these modes are also sensitive to the dimensionality of the problem. We computed QNM of BH in extra dimensions, in an effort to distinguish from those corresponding to 4D Einstein gravity, and found them to be different, which may be testable in future detectors.



Niladri Paul

Analytical and Semi-Numerical Techniques for Next Generation Observations of LSS

Large scale structure (LSS) is a well-developed but still rapidly growing field of cosmology starting from early 70s. On very large scales, the structure can be explained using linear perturbation theory [Mukhanov et al., 1992]. As one moves to smaller scales, higher order perturbation theories [Bernardeau et al., 2002, Shandarin and Zeldovich, 1989] and other non-linear theories, e.g., Peaks theory [Bardeen et al., 1986], Ellipsoidal collapse [Bond and Myers, 1996], Excursion set [Zentner, 2007], Halo model [Cooray and Sheth, 2002] and so on, become important. Eventually full N-body simulations [Barnes and Hut, 1986, Springel, 2005, Teyssier, 2002, Vogelsberger et al., 2014a,b] become essential to interpret the sophisticated cosmological data that we have today from SDSS, BOSS, PRIMUS, Pan-STARRS, UKIDSS, VIPERS [1] etc., and that will be available from the upcoming surveys like SKA, EUCLID, LSST [2] etc.

In the standard picture, galaxies form and live inside dark matter halos. The clustering of galaxies primarily depends on the mass of the halos they reside. To understand the formation and evolution of in a precise way, LSS it is important to model the effect of them. To do that one needs to approach the problem in several steps.

In the standard ΛCDM model, dark matter halos are building blocks of the structure of the universe we see today. So at first, one needs to model the clustering of halos which are biased tracers of the underlying dark matter density field. It has been seen in N-body simulations that this bias of halos depends on quantities other than halo mass such as halo formation history and halo concentration [Desjacques, 2008, Fakhouri and Ma, 2010, Gao et al., 2005, Hahn et al., 2009, Ramakrishnan et al., 2019, Sheth and Tormen, 2004, Tinker et al., 2005, Wechsler et al., 2006]. One needs to take into account all these effects in a systematic way when modelling the clustering of the halos. Another important thing to keep in mind is the halo exclusion [van den Bosch et al., 2007, 2013] which is the fact that two halos cannot come nearer than a certain distance, also has a significant contribution towards the clustering of halos.

Once the clustering of halos is properly modelled, one needs to understand the formation and distribution of galaxies inside those halos. There are many ways to do that. One of the popular techniques is semi-analytical modelling of galaxy formation [Gonzalez-Perezet al., 2018, Lacey et al., 2016, Zoldan et al., 2017], where researchers use simplified mathematical formulae to understand the baryonic processes affecting galaxy evolution, happening inside halos, e.g., star formation, supernovae feedback, AGN feedback, gas cooling, tidal stripping etc. Alternatively, one can statistically model the mapping between dark matter and galaxies assuming the halo model [Cooray and Sheth, 2002] using the Halo Occupation Distribution (HOD) [Berlind and Weinberg, 2002] or conditional luminosity function (CLF) approaches [Cacciato et al., 2013, Yang et al., 2008]. In the HOD formalism adopted in this thesis, one prescribes a statistical routine about how to populate the halos with galaxies depending on the halo and galaxy properties [Scoccimarro et al., 2001, Seljak, 2000]. It has been seen that it is necessary to split the galaxy population into centrals and satellites to describe both the correlation and abundance data of the galaxies accurately [Berlind et al., 2003, Vale and Ostriker, 2004, Yang et al., 2003, Zehavi et al., 2005, Zheng, 2004].

In this thesis, we discuss the halo model to address some questions in galaxy formation and evolution, and also discuss ways to improve the existing halo model. First, we applied the halo model within the order statistics framework to explore the possibility of reducing the number of parameters. We then applied the halo model to make a connection between optical properties and HI mass of the SDSS and ALFALFA galaxies. While doing these, we realised that there was room for significant development of the halo model and recalibration of the standard HOD parameters. We explored that in our third project. A brief description of the works is mentioned below.

[1] http://www.sdss.org/, https://www.sdss3.org/surveys/boss.php, http://primus.ucsd.edu/, http://pan-starrs.ifa.hawaii.edu/public/, http://www.ukidss.org/, http://vipers.inaf.it/

[2] https://www.skatelescope.org/, http://www.euclid-ec.org/, https://www.lsst.org/

Applying halo model to order statistics

There is a long debate in the literature whether the central galaxies in a cluster are special or just happen to be statistically the brightest galaxy in a group [Bhavsar and Barrow, 1985, Dobos and Csabai, 2011, Loh and Strauss, 2006, Schechter and Peebles, 1976, Tremaine and Richstone, 1977, Vale and Ostriker, 2008]. We used the halo model to explore the implications of assuming that galaxy luminosities in groups are randomly drawn from an underlying luminosity function. We showed that even the simplest of such order statistics models one in which this luminosity function $p(L)$ is universal naturally produces several features associated with previous analyses based on the central plus Poisson satellites hypothesis. These include the monotonic relation of mean central luminosity with halo mass, the Lognormal distribution around this mean, and the tight relation between the central and satellite mass scales. In stark contrast to observations of galaxy clustering, however, this model predicts no luminosity dependence of large scale clustering. We then show that an extended version of this model, based on the order statistics of a halo mass dependent luminosity function p(L—m), is in much better agreement with the clustering data as well as satellite luminosities, but systematically under-predicts central luminosities. This brings into focus the idea that central galaxies constitute a distinct population that is affected by different physical processes than are the satellites. We model this physical difference as a statistical brightening of the central luminosities, over and above the order statistics prediction. The magnitude gap between the brightest and second-brightest group galaxy is predicted as a by-product and is also in good agreement with observations. We propose that this order statistics framework provides a useful language in which to compare the halo model for galaxies with more physically motivated galaxy formation models.

Applying halo model for understanding the distribution of neutral hydrogen inside dark matter halos

Modelling the distribution of neutral hydrogen (H_I) in dark matter halos is important for studying galaxy evolution in the cosmological context. The number of H_I -selected galaxies has become quite substantial in recent years [Saintonge, 2007, Zwaan et al., 2003, 2005 a,b], and there has been a long effort in the community in exploring statistical techniques like halo model can be naturally extended to understand the H_I properties of galaxies [Padmanabhan and Kulkarni, 2017, Padmanabhan and Refregier, 2017, Padmanabhan, et al., 2016, 2017, Wyithe and Brown, 2010, Wyithe et al., 2009].

We used a novel approach to infer the H_I-dark matter connection at the massive end ($m_{HI} > 9.8 M_\odot$) from radio H_I emission surveys, using optical properties of low-redshift galaxies as an in-

termediary. In particular, we used a previously calibrated optical HOD describing the luminosity and colour-dependent clustering of SDSS galaxies and described the H_I content using a statistical scaling relation between the optical properties and H_I mass. This allows us to compute the abundance and clustering properties of H_I-selected galaxies and compare with data from the ALFALFA survey. We apply an MCMC-based statistical analysis to constrain the free parameters related to the scaling relation. The resulting best-fit scaling relation identifies massive H_I galaxies primarily with optically faint blue centrals, consistent with expectations from galaxy formation models. We compared the H_I -stellar mass relation predicted by our model with independent observations from matched H_I-optical galaxy samples, finding reasonable agreement. As a further application, we make some preliminary forecasts for future observations of H_I and optical galaxies in the expected overlap volume of SKA and Euclid/LSST.

Global analysis of luminosity and colour-dependent galaxy clustering in SDSS

There had been existing calibrations of Halo Occupation Distribution (HOD) in light of luminosity [Guo, et al., 2015, Zehavi, et al., 2011] and colour dependent clustering [Skibba and Sheth, 2009, Zentner et al., 2014, 2019] data. However, most of these calibrations suffer from the fact that they do not take into account the correlations between galaxy samples of different luminosity thresholds.

We presented HOD analysis of the luminosity- and colour-dependent galaxy clustering in the Sloan Digital Sky Survey, using a combination of clustering measurements in luminosity bins to perform a global likelihood analysis, simultaneously constraining the HOD parameters for a range of luminosity thresholds. We presented simple, smooth fitting functions, which accurately describe the resulting luminosity dependence of the best-fit HOD parameters. To minimise systematic halo modelling effects, we used theoretical halo 2-point correlation functions directly measured and tabulated from a suite of N-body simulations spanning a large enough dynamic range in halo mass and spatial separation. Thus, our modelling correctly accounted for non-linear and scale-dependent halo bias as well as any departure of halo profiles from universality, and we additionally accounted for halo exclusion using the hard sphere approximation. Using colour-dependent clustering information, we constrained the satellite galaxy red fraction in a model-independent manner which does not rely on any group-finding algorithm. We found that the resulting luminosity dependence of the satellite red fraction was significantly shallower than corresponding measurements from galaxy group catalogues, and we provided a simple fitting function to describe this dependence. Our fitting functions are readily usable in generating low-redshift mock galaxy catalogues, and we discuss some potentially interesting applications as well as possible extensions of our technique.

Conclusion

In the light of recent and upcoming data, halo model plays an important role in statistically understanding the galaxy formation and evolution process. Starting from the vanilla halo-mass only flavour, it is now being extended to include different higher order effects of structure formation to explain the observational data up to a few percent level accuracy. There is still room for improvement of the halo model both in the case of galaxies and gas. Our work on H_I halo model can be easily extended to incorporate the more accurate calibrations of optical HODs done in our recent work. To apply our new HOD calibrations to H_I halo model, we need to extend our calibrations towards fainter magnitudes. This work which is in progress, we use a hybrid

model combining analytical and direct simulation-based halo statistics at suitable scales. With the upcoming surveys, it will be possible to measure the higher-order statistics of H_I galaxies with far better accuracy. With those precision measurements, one can further improve the halo model of gas to better understand the formation and evolution history of galaxies. We are also planning to extend our halo model of galaxies and gas to incorporate the effects of tidal environments in the cosmic-web, which is going to play a crucial role in the upcoming era of big data.



Karthik Rajeev

Aspects of Semi-Classical Limit and the Backreaction Problem

The semi-classical limit of a quantum mechanical system, in this thesis, refers to the limit in which one part of the system is effectively described by a classical theory while the other is treated quantum mechanically.

There are several scenarios in physics where the semi-classical analysis is directly applicable and relevant. In this thesis, we focus on some of the important applications, which may be broadly classified into two classes: one in which the effectively classical part is the electromagnetic field, and the other in which the same is gravity. For instance, the former class includes the Schwinger effect; the theoretical prediction that in the presence of a constant electromagnetic field (which is treated classically), the vacuum decays via production of particle-antiparticle pairs. On the other hand, the cases in which gravity is treated as the classical part include Hawking radiation and particle production in expanding universe. While in the case of Schwinger effect, we have a mathematically consistent quantum theory that describes the whole system (electromagnetic field and the electron/positron), namely quantum electrodynamics (QED), there is no satisfactory quantum theory that incorporates gravity. Therefore, besides being an important area of research on its own, lessons can be learned from investigating Schwinger effect that may eventually shed light on more complicated scenarios, including the realization of a quantum theory of gravity.

The dynamics of the classical part is inherently affected by quantum fluctuations of the quantum mechanical part of the system, which it interacts with and leads to certain "quantum" modifications of the classical equation of motion. These modifications are generally in the form of expectation values or matrix elements of the appropriate quantum operators. However, among several other unresolved issues in this approach, it is not at all certain in which states this expectation value or matrix element should be evaluated and this has lead to several prescriptions for calculating the backreaction term leading to the 'backreaction problem' in semi-classical physics.

Often, we find that there are several mathematical similarities in the analysis of a class of different semi-classical systems. In particular, we shall see that quantum dynamics of a time dependent harmonic oscillator (TDHO) plays an important role in the study of particle production in a homogeneous and isotropic expanding universe as well as that in a homogeneous but time dependent electric field. Hence, in this thesis, several aspects of TDHO have been revisited. In particular, a novel approach proposed in the literature recently to study TDHO has been used to gain new insights that can be applied to the study of particle production and the associated backreaction.

A natural generalization of the Schwinger effect, which is referred to in the thesis as the 'generalized Schwinger effect', corresponds to the phenomenon of production of charged particle pairs from the vacuum, in the presence of a spatially homogeneous and time-dependent electric field. An important feature of the case of constant electric field is that, the mean number of pairs which are produced depends on the electric field and the coupling constant in a *non-analytic* manner, showing that this result cannot be obtained from the standard perturbation theory of quantum electrodynamics. When the electric field varies with time and vanishes asymptotically, the result may depend on the coupling constant either analytically or non-analytically. We investigate the

nature of this dependence in several specific contexts. We have shown that the dependence of particle production on coupling constant is non-analytic for a class of time-dependent electric fields, with the leading order non-analytic behaviour being controlled by a specific parameter which can be identified. We also demonstrate that, for another class of electric fields, which vary rapidly, the dependence of particle production on coupling constant is analytic. Finally, we describe what happens to these results when we go beyond the leading order, using some specific examples.

Following our analysis of generalized Schwinger effect, we compare several aspects of (a) particle production in a time dependent electric field with (b) particle production in an expanding Friedmann background. We provide an algebraic mapping between the differential equations describing particle production in these two cases. This mapping allows a precise comparison between (a) and (b), and we highlight several interesting features of both cases using this approach. We determine the form of the (equivalent) electric field corresponding to different Friedmann spacetimes and discover, for example, a time-dependent electric field, which in a specific limit, leads to a Planck spectrum of particles. We also discuss the conditions under which the particle production in an expanding background will be non-analytic in the parameter, which encodes the coupling to the curved spacetime, in close analogy with our analysis of the generalized Schwinger effect. We also study the situation in which both time dependent electric field and an expanding background are simultaneously present. We compute particle production rate in this context by several different methods paying special attention to its limiting forms and possible non-analytic behaviour. We also clarify several conceptual issues related to definitions of in-vacuum and out-vacuum in these systems.

As we have alluded before, a TDHO, i.e., a harmonic oscillator $q(t)$ with time-dependent mass $m(t)$ and a time-dependent (squared) frequency $\omega^2(t)$ occurs in the modelling of several physical systems including the cases mentioned above. It is generally believed that systems with $m(t) > 0$ and $\omega^2(t) > 0$ (normal oscillator) are stable while, systems with $m(t) > 0$ and $\omega^2(t) < 0$ (inverted oscillator) are unstable. However, we show that it is possible to represent the same physical system either as a normal oscillator or as an inverted oscillator by a redefinition of dynamical variables. While we expect the physics to be invariant under such redefinitions, it is not obvious how this invariance *actually* comes about. We study the relation between these two — normal and inverted — representations of an oscillator in detail, both in Heisenberg and Schrdinger pictures to clarify several conceptual and technical issues. The situation becomes more involved when the quantum oscillator $q(t)$ is coupled to another (semi) classical degree of freedom, say $C(t)$, and we want to consider the backreaction of the quantum system $q(t)$ on $C(t)$, in the semi-classical approximation. We provide a simple prescription for the backreaction based on energy conservation, and study the dynamics of the full system in both normal and the inverted oscillator representation. This backreaction equations governing the semi-classical dynamics of $C(t)$ obtained in this approach coincide with the so-called 'in-in' prescription for backreaction. Under a transformation from normal to inverted oscillator representation of the quantum system, the physics remains invariant, as is desired, but there are some extra subtleties which we clarify. The implications of these results for quantum field theory in cosmological backgrounds are also discussed briefly.

The backreaction prescription that we have just motivated, based on energy conservation can also be derived from the Heisenberg equation of motion for C by replacing any operator that acts on the Hilbert space associated with q by its expectation value in the so-called 'in-vacuum' of q. This approach may seem rather ad hoc, but it can actually be given a more formal foundation. So we reformulate this approach by considering the quantum evolution of a TDHO along contours in complex $t-$plane. We first provide a simple derivation of the differential equation for the functional determinant, appearing in the path integral propagator for this system. Following this, the backreaction equation for a classical variable C coupled to the TDHO is obtained *directly* from

the path integral formalism. It is explicitly shown that when the contour corresponds to that of the Schwinger-Keldysh formalism, one retains the 'in-in' backreaction equation. For another choice of contour, one obtains the 'in-out' backreaction equation.

The vacuum fluctuations of the quantum mechanical part of a system, which are relevant in the semi-classical analysis, is encoded in the quantum correlators, viz., Feynman propagator, Whitman function, etc. However, in the presence of a general classical background, the notion of a unique vacuum for the quantum field ceases to exist. Different choice of vacua, in general, lead to completely different physics. The quantum correlators can be used to compare the different physical properties of such inequivalent vacua. We next take up the study of these aspects.

In flat spacetime, two inequivalent vacua states, which arise rather naturally are the Rindler vacuum $|R\rangle$ and the Minkowski vacuum $|M\rangle$. We discuss several aspects of the Rindler vacuum, concentrating on the propagator and Schwinger (heat) kernel defined using $|R\rangle$, both in the Lorentzian and Euclidean sectors. We start by exploring an intriguing result (due to Candelas and Raine), viz., that G_R, the Feynman propagator corresponding to $|R\rangle$, can be expressed as a curious integral transform of G_M, the Feynman propagator in $|M\rangle$. We show that this relation actually follows from the well-known result that, G_M can be written as a periodic sum of G_R, in the Rindler time τ, with the period (in proper units) $2\pi i$. We further show that the integral transform result holds for a wide class of pairs of bi-scalars $\{F_M, F_R\}$, provided F_M can be represented as a periodic sum of F_R with period $2\pi i$. We provide an explicit procedure to retrieve F_R from its periodic sum F_M, for a wide class of functions. An example of particular interest is the pair of Schwinger kernels $\{K_M, K_R\}$, corresponding to the Minkowski and the Rindler vacua. We obtain explicit expression for K_R and clarify several conceptual and technical issues related to these biscalars both in the Euclidean and Lorentzian sector. In particular, we address the issue of retrieving the information contained in all the four wedges of the Rindler frame in the Lorentzian sector, starting from the Euclidean Rindler (polar) coordinates. This is possible but requires four different types of analytic continuations, based on one unifying principle. Our procedure allows generalization of these results to any (bifurcate Killing) horizon in curved spacetime.

Following our analysis of quantum field theory in flat spacetime, we discuss several aspects of quantum field theory of a scalar field in a Friedmann universe. We begin by showing that it is possible to map the dynamics of a scalar field with a given mass, in a given Friedmann background to another scalar field of a different mass in another Friedmann universe. In particular one can map the dynamics of (i) a massless scalar field in a universe with power-law expansion to (ii) a massive scalar field in the de Sitter spacetime. This allows us to understand several features of either system in a simple manner and clarifies several issues related to the massless limit. We relate the Euclidean Greens function for the de Sitter spacetime to the solution of a hypothetical electrostatic problem in $D = 5$ and obtain, in a very simple manner, a useful integral representation for Greens function. This integral representation is helpful in the study of several relevant limits and in recovering some key results which are –though known earlier– not adequately appreciated. One of these results is the fact that, in any Friedmann universe sourced by a negative pressure fluid, the Wightman function for a massless scalar field is divergent. This shows that the divergence of Wightman function for the massless field in the de Sitter spacetime is just a special limiting case of this, more general phenomenon.

Another useful quantity in the study of quantum fields in a Friedmann universe is the power spectrum of quantum fluctuations. We provide a generally covariant procedure for defining the power spectrum of vacuum fluctuations in terms of the different Killing vectors present in the spacetime. This allows one to study the interplay of the choice of vacuum state and the nature of the power spectrum in different coordinate systems in the de Sitter universe in a unified manner.

As a specific application of this formalism, we discuss the power spectra of vacuum fluctuations in the static (and Painlev) vacuum states in the de Sitter spacetime, and compare them with the corresponding power spectrum in the Bunch-Davies vacuum. We demonstrate how these power spectra are related to each other in a manner similar to the power spectra detected by the inertial and Rindler observers in flat spacetime. This also gives rise to a notion of an invariant vacuum noise in the corresponding spacetimes which is observer independent. In addition, several conceptual and technical issues regarding quantum fields in general cosmological spacetimes are clarified as a part of this study.

A brief chapter-wise summary of the thesis is given below:

1. Chapter 1 is the introductory part, comprising the motivation of the thesis and a review of some necessary background material.

2. In Chapter 2, generalized Schwinger effect is studied. We investigate the nature of dependence of the mean number of pairs produced on the electric field strength and the coupling constant, in several specific cases. We have shown that for a class of electric fields, the non-analytic behaviour, at the leading order, is controlled by a single parameter which occurs in the theory.

3. In Chapter 3, we introduce an algebraic correspondence between particle production in (a) time dependent electric field, and (b) expanding Friedmann background. This mapping is applied to different interesting special cases of time dependent electric field/scale factor.

4. In Chapter 4, we show that when a physical system can be represented by a TDHO, by a redefinition of dynamical variables, it is possible to represent the same system either as a normal oscillator or as an inverted oscillator. The implication of this on the backreaction problem is analysed.

5. In Chapter 5, we describe the path integral description of a TDHO evolving along a complex time contour. We demonstrate that this description allows us to derive both 'in-in' and 'in-out' backreaction prescriptions in a unified manner from the standard path integral formalism.

6. In Chapter 6, the Schwinger kernel as well the Feynman propagator of the Rindler vacuum in flat spacetime are explored both in the Euclidean and Lorentzian sector. We have also demonstrated that the origin of an intriguing relation between Feynman propagator in the Rindler vacuum and that in the Minkwoski vacuum, due to Candelas and Raine, is the thermal nature of the latter in relation to the former.

7. In Chapter 7, we discuss several aspects of quantum field theory of a scalar field in a Friedmann universe. In particular, we investigate the divergence or well-behavedness of Wightman function for the massless field. Our study shows that the divergence of Wightman function for the massless field in the de Sitter spacetime is a special case of a general phenomenon.

8. In Chapter 8, we provide a covariant, geometric procedure for defining the power spectrum of the vacuum fluctuation in terms of Killing vector field of the spacetime. Application of this formalism to Friedman universe is provided.

9. We conclude the thesis with Chapter 9, wherein we provide the summary and present the future outlook.



Shabbir I. Shaikh

Study of Cosmic Microwave Background: Anomalies and Weak Lensing

Cosmic Microwave Background (CMB) is one of the cleanest probes available to study the universe. The physics governing the generation of CMB and its anisotropies is well understood. Many ground-based, balloon-borne, and space-borne experiments have studied CMB temperature and polarization anisotropies. These studies, combined with other cosmological probes, have given a broadly consistent picture of our observable universe described by the ΛCDM model of the universe.

Statistical homogeneity and statistical isotropy (SI) of the universe are two underlying assumptions of cosmology. Measurements of CMB by all-sky, space-based CMB missions, WMAP and *Planck*, have been used to test the hypothesis of SI of CMB fluctuations. These analyses have shown that there are anomalous features in CMB temperature anisotropy data that do not conform to our assumptions or expectation. One of the anomalies referred to as the *Cosmic Hemispherical Asymmetry* (CHA), is a telltale sign of departure from SI that manifests as a dipolar breakdown of statistical isotropy. In this thesis, we use the Bayesian inference to explore the nature of CHA. We also assess the possible connection between CHA and another anomaly, *Power Suppression*, the putative lack of large scale power in the temperature data compared to what is expected in the concordance model.

CMB temperature anisotropy measurements by *Planck* are limited by cosmic variance up to multipoles $l \approx 1500$ (≈ 5 arcmin angular scale). However, the measurements of CMB polarization anisotropies have not attained this status. Especially, the primordial B-mode polarization signal, which is an important evidence for the models of inflation, has not been detected yet. Various other signals of astrophysical and cosmological origin act as a contaminant to the primordial B-mode signal. B-mode polarization signal from galactic dust and the B-mode signal introduced by the lensing of CMB photons form a major part of B-mode signal observed by the instrument. While it is important to understand non-primordial B-mode signatures to recover the primordial B-mode signal, these are also interesting in their own right. Weak lensing of CMB photons by large scale structure probes the integrated mass density between the current epoch and the epoch of the last scattering of CMB. A stochastic gravitational wave background (SGWB) also affects the CMB anisotropies via weak lensing. Unlike weak lensing due to large scale structure, which at linear order only deflects photon trajectories, an SGWB has an additional effect of rotating the polarization vector along the trajectory even at linear order. We explore the nature of this effect and use it to constrain SGWB.



Javed Rana Sk.

Strategies for Searches of Electromagnetic Counterparts of Gravitational Wave Signals

Multi-messenger astronomy has begun with the recent observation of the binary neutron star merger event GW170817 in the electromagnetic spectrum and with gravitational wave (GW) radiation. Many new discoveries related to GWs are yet to happen. Worldwide, a significant investment has been made in programmes (e.g., BlackGem, GOTO, ZTF/GROWTH, VLA, GMRT, ATCA, Swift, Fermi, INTEGRAL, etc.) dedicated to the search for the electromagnetic counterparts of GW sources. At the same time, the electromagnetic follow-up of compact binary mergers like GW170817 poses challenges such as (i) we may not be on-axis to the short gamma-ray burst from such a merger, (ii) GW sky localization is large in area and volume, (iii) kilonovae are fast fainting objects and daytime sky is inaccessible, etc. The thesis is on the improvement of follow-up strategies for the observation in different electromagnetic bands to make the search easier.

The follow-up observation in the electromagnetic spectrum of GW transient sources is crucial for developing a complete astrophysical understanding of those phenomena. Various gamma ray burst (GRB) detectors, and more notably the ground–based GW detectors, typically have large uncertainties in the sky positions of detected sources. We present algorithms for better scheduling of such follow–up observations in order to maximize the probability of finding the electromagnetic counterpart, based on all–sky probability distribution of the source position. We consider realistic observing scenarios, and address some of the challenges in the follow-up observations of electromagnetic counterparts. We examine difficulties arising from airmass, slew of telescope, diurnal cycle, telescope pointing limitations, available observing time, and the rising/setting of the target.

In order to identify the rapidly-fading, optical transient counterparts of GW sources, an efficient follow-up strategy is required. Since most ground-based optical telescopes aimed at following-up GW sources have a small field-of-view (FOV) as compared to the GW sky error region, we focus on a search strategy that involves dividing the GW patch into "tiles" of the same area as the telescope FOV to strategically image the entire patch. We present optimal algorithms factoring in the effects of airmass, telescope slew, and setting and rising constraints into the scheduling algorithm in order to increase the chances of identifying the GW counterpart. Initially we proposed *GrAr*, *EnAr* and *SeAr* algorithms to account for setting and rising. Later, we proposed two separate algorithms: the *airmass-weighted* algorithm, a solution to the Hungarian algorithm that maximizes probability acquired in the available observation time while minimizing the image airmass, and the slew-optimization algorithm that minimizes the overall slew angle within the observation schedule using the travelling salesman algorithm. We use simulations to demonstrate that our proposed algorithms outperform the default greedy observing schedule used by many observatories. Further, we demonstrate that as compared to the greedy algorithm, the *EnAr* and *airmass-weighted* algorithms can acquire up to 20% more probability and 30 sq. deg. more in areal coverage for skymaps of all sizes and configurations. Our algorithms are applicable for follow–up of other transient sources with large positional uncertainties, like (*Fermi*–detected) GRBs, and can easily be adapted for scheduling radio or space–based X–ray followup.

Kilonovae and radio afterglows of neutron star merger events have been identified as the two most promising counterparts, of these GW sources, that can provide arcsecond localization. While several new and existing optical search facilities have been dedicated to finding kilonovae, factors

such as dust obscuration and the daytime sky may thwart these searches in a significant fraction of GW events. Radio-only searches, being almost immune to these factors, are equally capable of finding the counterparts and in fact offer a complementary discovery approach, despite the modest fields of view for many of the present-day radio interferometers. Such interferometers will be able to carry out competitive searches for the electromagnetic counterparts through the galaxy targeting approach. Adapting and improving on an existing algorithms, we present here a method that optimizes the placement of radio antenna pointings, integration time, and antenna slew. We simulate 3D GW localizations to find the efficacy of our algorithm; with substantial improvements in slew overhead and containment probability coverage, our algorithm performs significantly better than simple galaxy-rank-ordered observations. We propose that telescopes, such as the Very Large Array, MeerKAT, Australia Telescope Compact Array and the Giant Metrewave Radio Telescope, having fields of view $\lesssim 1$ deg^2 and searching for the counterparts of nearby GW sources in localization regions as large as tens of square degrees or larger, will especially benefit from this optimized galaxy-targeting approach for electromagnetic counterpart searches.

To understand the merger environment and the mechanism behind the jet formation of a BNS merger, we need to observe the prompt emission, and the pre-merger emission during the merger. Capturing the prompt emission in x–ray and optical is extremely challenging, because of unknown trigger time of the GW signal and the poor localization of the GW source. We developed a pipeline to send alert of the BNS merger to the electromagnetic observers prior to the merger. To develop the pipeline, we focused on two main parts of the advance alert problem. First is the detection of the inspiral signal of a BNS system from the noisy data of the GW detectors. Second is the localization of the source on the 3D sky for the follow-up observation. We build template banks for searching signal in the time series data, where the waveforms in the bank have f_{lower} (lower cut-off frequency) at 10 Hz and the f_{upper} (upper cut-off frequency) at $\sim$30 Hz. In order to remove the glitches from the data and test the consistency of the signal with the template, we calculate the chi-square signal-based discriminator. The success of capturing the prompt emission from the merger of BNS system highly depends on the area of the GW-localization and the response of the telescopes. We finalize the possible location of the GW source by localizing the event at least 20 seconds before the merger.

LIGO-India will be a 2nd generation detector in India (one of the three LIGO detectors, with the other two in the US), and will start observation around 2025. LIGO-India, as part of a network of GW detectors, will make immense improvement in the localization of the gravitational sources. We studied the increase in the rate of detection of GW events for networks once LIGO-India comes online. The chance of finding sources increase across the sky, but especially, in the less sensitive region in the sky of the Hanford-Livingston LIGO network, when we add LIGO-India to the network.

FACILITIES

COMPUTER CENTRE



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

The hardware and devices currently managed by the computing facility include, 320 servers and desktops, 85 laptops, 78 printers and scanners, two large HPC systems, and over a PetaByte 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 for its members and visiting associates amount to nearly 600.

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

1. High Performance Computing Cluster

IUCAA is having two independent HPC clusters with a different purpose, namely Pegasus and SARATHI.

The Pegasus Cluster is newly implemented to serve increasing computing requirement, has 60 compute nodes, each node is having 32 cores and 384 GB RAM. It uses infiniband EDR (100Gbps) as an inter-connect, and Portable Batch System (PBS) as a job scheduler. For visualisation purposes, there are two dedicated graphics node equipped with NVIDIA Tesla P100 GPU cards. The cluster is attached to a 1PB parallel file system (Lustre), which is capable of delivering 15GBps throughput. Theoretical computing speed of the Pegasus Cluster is 100 TF. The Pegasus, cluster has been utilized by more that 45 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 our 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.

2. HPC clusters listed in Top Supercomputers in India

Sarathi Cluster Phase III, Pegasus Cluster, and Sarathi Cluster Phase II are listed at 17 th , 25 th and 27 th rank respectively in the list of top Supercomputers in India published on January 31, 2020. The list is maintained and supported by CDAC's Terascale Supercomputing Facility (CTSF), CDAC, Bangalore. The list is available at http://topsc.cdacb.in/jsps/jan2020/index.html

3. 22 TR Chiller for Old Data Centre

The Chiller serving the old data centre, which is hosting the critical services like email server, Vroom cluster, storages, authentication server, etc., is about nine years old, and the component failure rate has increased. For all these services, cooling plays a crucial role. Hence, to maintain 99.99% uptime, we have installed an additional BlueBox Chiller of 22 TR cooling capacity.

4. CCTV Surveillance System

We have installed a closed-circuit television (CCTV) camera system to enable surveillance on computer hardware and data centre NON-IT equipment as well as for security. Currently, the Library Open Office, TV Room (allocated for visitors), Computer Centre Corridor, New Data Centre Corridor, and BMS terrace area are under CCTV surveillance.

5. TAPE Archival Storage for MALS

MALS is one of the ten extensive surveys being carried out with the MeerKAT telescope in South Africa. The data are being transferred from South Africa to IUCAA through tapes (LTO7 or better) and processed in IUCAA by the MALS team. The MALS data products will be served to the international community from IUCAA. We have implemented a TAPE archival system to archive generated data products. The archival system contains two HPE Store Ever LTO-8, 100 X 15 TB LTO-7, and 20 X IBM LTO-7 tape drives. To store these tape drives, we have a dedicated, waterproof and fireproof tape container.

6. FTP and Download Server

The existing FTP and download servers were very old and out of support. Both the servers had limited storage space to host/download the data. Hence, we have migrated FTP and download servers on new servers having larger storage capacity.

7. Up-gradation of VMware Software

We have four ESX host servers, and its consolidated resources like CPU, RAM, etc. are being shared among all the virtual machines, being used by the administrative staff, visitors, and students. Since the number of staff members and users have increased, and they need latest operating systems, such as Windows 10, CentOS-7.x with USB redirection facility, up-gradation of existing VMware software, hardware and storage has been carried out with addition of two ESX hosts with high-end configuration, and expansion of 3PAR storage with additional 50 TB

8. UPS Battery Replacement

IUCAA has two independent data centres and both host very critical services. The power supply to these data centres is routed through UPS to provide uninterrupted services. For the new data centre, we have 280 KVA ABB UPS, whereas for the old data centre, we have 120 KVA Vertiv UPS. Batteries of these UPS were about four years old. Hence, we have replaced batteries of both the UPS.

9. PCs for Administration Users

Earlier, the administration users were using zero thin client and monitors. The setup was about six years old, and the component failure rate was high during the last year. Hence, we have replaced all zero thin clients in administration block with new HP 600 G5 All-in-One desktops. They provide additional productivity time by enabling uninterrupted local work environment during maintenance activity.

10. Online Transport Request Application

We have designed a web application to facilitate the request and allotment of the transport facility. The application accepts necessary inputs such as date, time, email, number of people, etc., and forwards the request to the transportation section for review and allocation of an appropriate vehicle.

11. Network Migration from iucaa.in to ligo-india.in

We have implemented a dedicated domain ligo-india.in, dedicated for the LIGO – India project. For this, we have provided separate network connectivity from Network Operations Centre (NOC) room to a rack in the new data centre. We configured network migration from iucaa.in to ligo-india.in and set up the Cisco 3600 router for BGP peering for ISPs (NKN and TATA VSNL).

In order to increase the Wi-Fi coverage and connection stability, we have installed six additional Ruckus R 720

access points in Nalanda Hostel.

HP LaserJet 700 Multi-function printer (Qty. 1), HP Elite Desktop 800 G3 with Monitor (Qty. 20), HP 600 G5 All-in-one (Qty. 45), HP ProBook 440 G6 Laptop (Qty. 4), and MacBook Pro (Qty. 4) were acquired for the academic community, visitors and administrative officers.

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The Computing Facility employs 8 personnel, who carry out the daily functions that include:

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

2. Framing policy documents and finalizing them in consultation with the Computer Users' Committee members.

3. Drawing up specification of the RFP (Request for Proposal) tender document for IUCAA IT required to be purchased, and oversee all purchases related procedure and follow up.

4. Maintenance of IT hardware in the campus, including servers, desktops, mobile computing equipment, printers, etc.

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

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

7. Configuration and management of data backups.

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

9. Administration of Ruckus wireless network covering the entire office as well as residential campus. Providing end users support for Wi-Fi devices such as laptops, and 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 centre consumable items, 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 Visiting Associates.

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

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

17. Hardware maintenance and general system administration of clusters in coordination with OEM.

18. Assisting Estate Department with Data Centre management activities.

19. Architecting new hardware solutions to address operational needs.



Staff of the Computing Centre (The High Performance Computing clusters are seen in the background)



High Performance Computing clusters, Perseus, Pegasus, and Sarathi



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

(All pictures are credited to Shashank Tarphe (IUCAA))

INSTRUMENTATION

Quantum metrology for precision measurements

IUCAA has recently conceived Precision and Quantum Measurement lab (PQM-lab), as symbolically represented in the picture below. This initiative led by Subhadeep De have experimental research interests on:

(i) Precision measurements to probe fundamental aspects of science such as constancy of the dimensionless fundamental constants, geodesy, violation of the fundamental symmetries, etc.

(ii) Quantum metrology on ultra-stable optical reference to support high-resolution precision spectroscopy, communication etc.

(iii) Developing quantum enhanced technologies to support national mission on quantum technology and applications (NM-QTA).



At a glance picture - experimental facilities to be developed at the Precision and Quantum Measurement lab (PQM-lab) and its focus area for pursuing science and technology. The experimental set-up shall consist of a trapped ytterbium-ion optical atomic clock, ultra-stable reference optical oscillator, and optical frequency comb for studying quantum metrology, precision measurements and developing quantum-phenomena based technologies

In addition to the above-mentioned scientific interests, overall visions of the PQM-lab are the following:

Since goals of this laboratory shall lead to fruitful international collaborations, which will enhance global visibility of IUCAA in the areas of experimental atomic-molecular-optical physics having an overlapping interest with the astronomy and astrophysics on the way to develop a state-of-the-art experimental setup, which will result to spin-off indigenously developed niche technical instruments and electronic hardware, which can be commercialized to the Indian industries and will help the country towards import substitution.

This laboratory shall develop highly skilled and trained manpower, at the level from undergraduate, Ph.D.s, and research associates, in the areas of Atomic Physics, Laser Physics, Theoretical Modelling, Electronic and Mechanical Instrument Sciences. This human resource will be useful for all the mega science projects in India and strengthen overall scientific development of the country.

IUCAA LIBRARY

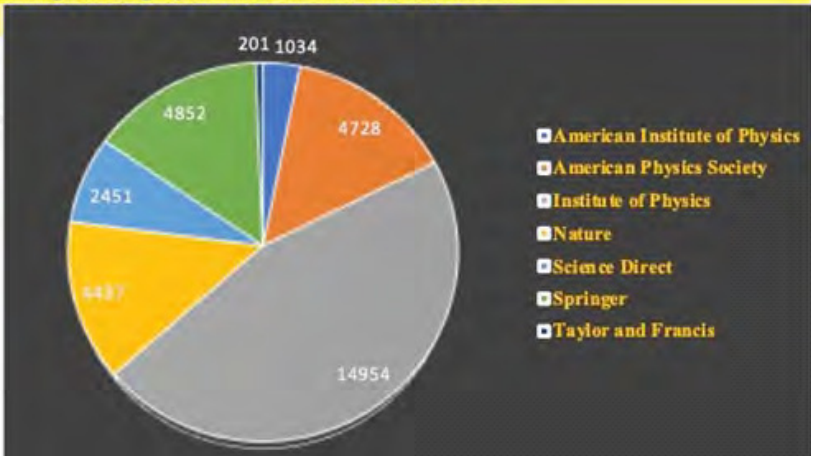
The IUCAA library provides access to a comprehensive collection of books and journals in astronomy, astrophysics and related areas. During the year, the library has added 41 Books, and 267 E-Books, published by the Oxford University Press, and Springer Physics. The astronomy E-Books collection for the year 2019 is 299, and renewed its subscription to the Grammarly Premium software. With a subscription base of 79 journals, the library also has purchased the digital archive collections of Nature, Classical and Quantum Gravity, and Journal of Cosmology and Astroparticle Physics. In addition to the E-Journal subscriptions, the library continued to receive access to the following seven e-resources by courtesy of 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 usage of E-Journals and E-Books is depicted below.

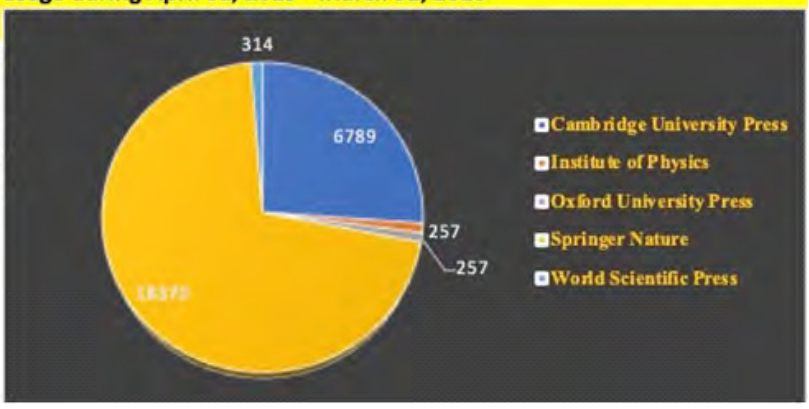
E-Journals usage during April 01, 2019 - March 31, 2020

Resource	Count
American Institute of Physics	1034
American Physics Society	4728
Institute of Physics	14954
Nature	4437
Science Direct	2451
Springer	4852
Taylor and Francis	201



E-Books usage during April 01, 2019 - March 31, 2020

Resource	Count
Cambridge University Press	6789
Institute of Physics	257
Oxford University Press	257
Springer Nature	18370
World Scientific Press	314



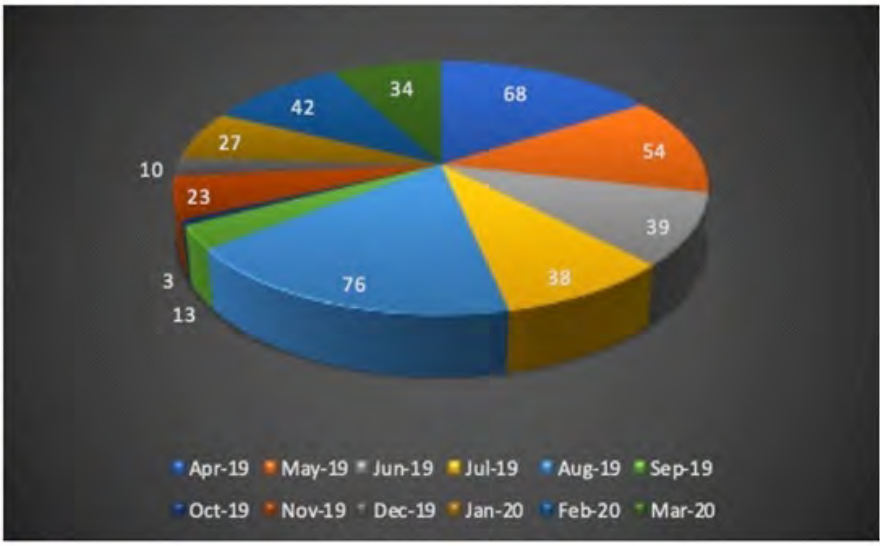
The EZproxy access and authentication software has been deployed by the library to facilitate off-campus access to all the e-resources subscribed by the library. The facility is accessed by IUCAA users and Visiting Associates.

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
- Institutional Repository
- Nature
- New Scientist
- Physics Today
- Physics Education
- Popular Science
- Science Direct
- Springer Nature
- Taylor and Francis
- IUCAA Institutional Repository
- Web of Science
- World Scientific

EZproxy usage during April 01, 2019 - March 31, 2020

Month	Count
Apr-19	68
May-19	54
Jun-19	39
Jul-19	38
Aug-19	76
Sep-19	13
Oct-19	3
Nov-19	23
Dec-19	10
Jan-20	27
Feb-20	42
Mar-20	34
	427



The library team of five professionals facilitated the following activities and services:

1.Document Delivery Service for articles and book chapters – fulfilled 195 article requests received from 110 users and 11 book chapters requested by 7 users.

2.Processed 13 page charge requests.

3.Assisted 4 users in ordering 15 books from their contingency grant.

4.Plagiarism report using Urkund for research papers.

5.The library YouTube Channel: 206 videos have been uploaded. The subscriber base is 3,853, and during the year, there have been a total of 79,362 views.

6.Assisted Visitor Services in the compilation of the research write up and publications by Visiting Associates.

RADIO PHYSICS LAB

Radio Physics Lab (RPL) is a unique facility at IUCAA, where students from physics and engineering background can explore their skills and learn Astronomy and Astrophysics. Our aim has been to design and demonstrate the important experiments related to Radio Astronomy in an innovative way for scientific purposes and for educating students, teachers, educator enthusiasts, and the general public. The areas being pursued here range from cosmic ray detection to communication using LASERs and Raman Spectroscopy. Apart from these, RPL is also active in public outreach. Public lectures and demonstrations are organized for students, and astronomy and science enthusiasts. Radio Astronomy Winter School (RAWS) is conducted for under-graduate and post-graduate students, introducing them to the field of Radio Astronomy, in collaboration with other departments. RPL has been conducting many workshops and training for teachers and students. Over the past 12 years, several students have been benefited from this platform. More than 90 percent of students are pursuing a PhD degree in astronomy and related areas, and many are currently active in the research field in some form or the other. Following are the details of experiments and activities carried out by RPL:

Radio Astronomy Winter School

Radio Astronomy Winter School (RAWS) has been organized every year, and this year it was organized in collaboration with RPL, IUCAA; Astronomy Centre for Educators (ACE), IUCAA; and RPL, NCRA. The school is largely meant for under-graduate and first year post-graduate students in Physics/Electronics/Astronomy, and Engineering, and for educators. Bright and highly motivated high school/junior college students involved in amateur astronomy have been also encouraged to apply. Through lectures and hands-on radio astronomy experiments, the school exposes the participants to astronomy in general and radio astronomy in particular. The school has been immensely popular, and so far eleven such schools have been organized since 2008. The hands-on experiments included: (i) Observations of Sun with the 4 m telescope to determine the antenna power pattern, (ii) Observations of HI 21 cm line to neutral hydrogen from the Galaxy, and (iii) Measuring Noise (Johnson Noise) in an electronics system. These experiments are designed to educate the students about techniques, and instrumentation used in radio astronomy. This year, we also invited teachers/educators from universities to attend the winter school and mentor the students.





Workshop on Engineering Application in Astronomy

A workshop on Engineering Applications in Astronomy was organized by IUCAA, in collaboration with Vishwakarma Institute of Technology (VIT), Pune, during August 19 - 24, 2019 at VIT Campus, Pune. This was the third in a series of workshops being organized with the primary aim to create awareness among engineers about the field of astronomy, and present the challenging opportunities available to the engineering students. Around 40 participants were selected from different branches of engineering, and from different parts of the nation. The experiments were designed by RPL and Instrument Department for the workshop.

Workshop on Small Affordable Radio Telescope

A one day Workshop on Small Affordable Radio Telescope (ASRT) was conducted at VIT, Pune, by Antariksh Astro Club of VIT, Pune, with the help of RPL. Our team members, Jameer Manur, and Ashish Mhaske were the resource persons. The first half of the day was focussed on the basics of Radio Astronomy and Radio Astronomy Instrumentation, and the second half was meant for the hands-on sessions. Around 45 students attended from Pune, Mumbai, and Jaipur.



Horn Antenna for 21 cm Hydrogen Line

The 21 cm hydrogen line is a spectral line emitted by atomic hydrogen. Since, hydrogen is the most abundant element in the universe, this makes the hydrogen line very crucial in the field of radio astronomy. A horn antenna has been designed for detecting this 21 cm line from our galaxy, and the structure of the galaxy can also be estimated. It has also made it possible to estimate the rotation curve of the galaxy. A primary limitation of radio astronomy is noise, either man-made or naturally occurring. Hence, we require new techniques to reduce noise from our detector. The horn antenna is able to pick up radiation from the hydrogen clouds in our galaxy while suppressing terrestrial interferences due to the low side lobes of the antenna. The antenna is easy to handle, and is superior to a parabolic dish in terms of noise performance.



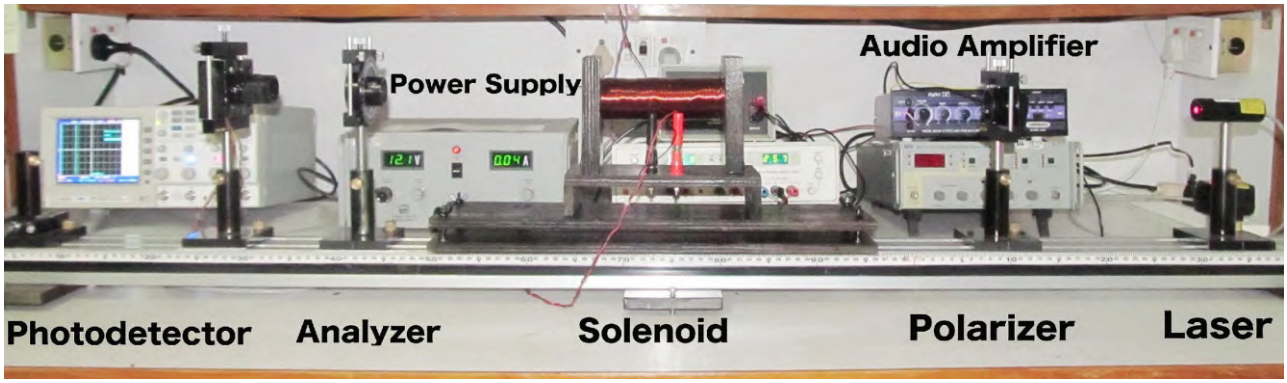
This is a dual mode conical horn antenna. It is easy to construct as compared to other antennas with similar noise performance. Software Defined Radio (SDR) receivers were used with great success. The limitation of the conventional radio is its inability to configure the hardware. SDR can be configured to serve any purpose of the user. Such a receiver was implemented successfully for detection of hydrogen line. Important techniques, like Dicke switching, were implemented with SDR. This has made the telescope low cost and hence, accessible to amateur

radio enthusiasts. The antenna has proven to be very reliable. It will be used in MSc practical in radio astronomy, as well as in Radio Astronomy Winter Schools. The antenna has also been used to demonstrate principles of radio astronomy to amateurs as well as for public outreach.

Faraday Rotation Experiment for Communication

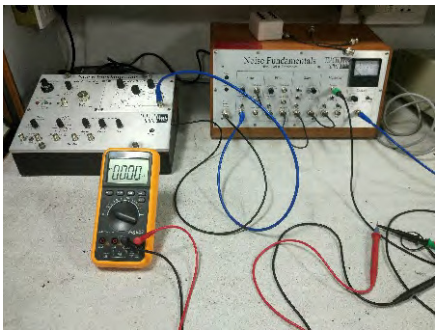
The polarization of light is quite frequently observed in nature, and with other properties like amplitude, frequency and phase of an electromagnetic (EM) wave, it constitutes one of the most fundamental quantities, which completely describes it. In physics and optics, the polarization of light is studied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

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



The laser will act as a carrier and the audio is given as a modulating signal to the solenoid, the audio signal modulated in the presence of Faraday material (TGG). The power requirement is very low as compared to the existing analogue modulation techniques. The system is successfully working over the audio bandwidth.

Noise Fundamental Experiment



The Noise Fundamental Experiment is one of the most important tools to study the noise in an electronic system and in any instrument. Many a time, we are restricted by the noise in the system. The noise present in all electronic signals limits the sensitivity of many measurements. The thermal noise generated by a resistor at room temperature or the shot noise in diode and transistor can be studied by using this setup.

The noise can be observed on the display of an oscilloscope, and also manipulate it by changing the parameter of noise, like temperature, bandwidth, etc.

Cosmic Ray Muon Detector

The Cosmic Ray Muon Detector (CRMD) is a particle detector, which can detect and observe by-products of cosmic ray particles, which were created and accelerated by very violent mechanisms in the universe. The

CRMD at IUCAA RPL is one of its kind, and was built in 2011 by undergraduate level students. It is the only detector of its type running in entire Asia. The material to build the detector was imported from FERMILAB, USA.



This detector is used to take readings of constant muon flux, and determine mean muon lifetime. It is quite a rich experiment as it enables students to not only study astro-particle physics, but also quite a lot about nuclear and particle physics in general. Mean muon lifetime also serves as a test for Einstein's special theory of relativity.

Since 2012, the detector has been used for experiments in Savitribai Phule Pune University MSc Astronomy and Astrophysics specialization course, as well in Radio Astronomy Winter School.

Raman Spectroscopy

The Raman Spectroscopy is one of the important tools in physics and chemistry to identify the elements, and is an inelastic scattering of monochrome light, and the frequency of light changes upon interaction with a sample. Frequency of the re-emitted photons is shifted up or down in comparison with original monochromatic frequency, which is called the Raman Effect. This shift provides information about vibrational, rotational, and other low frequency transitions in molecules. Raman Spectroscopy can be used to study solid, liquid and gaseous samples.



In this experiment, we see the stokes and anti-stokes line on both side, we could see the Raman scattering in this experiments. A powerful green (532 nm) laser is used, and an astronomical grade cool CCD camera is used to detect the Raman scattering.

Other Experiments

Many other small experiments, like Noise figure measurement of radio frequency amplifiers, Antenna radiation pattern measurement are done in RPL. Solar observations are taken at 10 GHz with a satellite TV dish antenna. This is a low cost and easily available radio telescope set up.

National Science Day

National Science Day is an important event in IUCAA. It is the time of the year when IUCAA is open to the general public all day long, and the staff here exhibit and explain the experiments and activities which are conducted in IUCAA, to the general public. This year, RPL, in association with ACE, IUCAA has demonstrated, and explained various astronomy, and physics related experiments at the new TLC building. In addition to the horn antenna, 3 m parabolic radio telescope, ASRT, Faraday Rotation, Different types of Antennas, and Muon detector were presented. The recently discovered Saraswati Supercluster LED model, which was made by RPL project students, was also presented. We have exhibited many posters and working models based on astronomy and radio astronomy, where general public can understand it very easily.



A brief explanation of the history of radio astronomy, detailed working of a radio telescope represented in block diagram form an easy understanding for the general public, and different types of radio telescopes working on different types of bands around the world were also displayed. The volunteers representing RPL were from VIT, VIIT, Cummins, and Fergusson College, Pune.

Jameer Manur gave a talk on the First Image of Black Hole, and Pratik Dabhade and Ashish Mhaske jointly gave a talk on Next-generation Radio Astronomy.

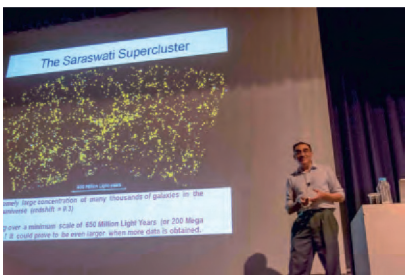
Public Outreach

RPL gives special attention to public outreach, and is open to enthusiastic individuals for any help/advice they require regarding astronomy related activities. RPL members deliver informative lectures related to astronomy and instrumentation in astronomy in schools and colleges (as seen in fig.) to make students aware of the career opportunities in the field of astronomy. They also give instructions to the students about the latest developments of this field.

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



Public Lecture on Saraswati Supercluster



Joydeep Bagchi and team have given lectures on their recent discovery of Saraswati Supercluster, at many institutes, including Vishwakarma Institute of Technology, Pune; IUCAA, Pune; IISER, Tirupati; IIT, Indore; and Satellite Application Centre, ISRO, Ahemdabad.



MSc Practicals

MSc students of the Department of Physics and Space Science of the Savitribai Phule Pune University are supposed to perform experiments as a part of their curriculum, and they have to appear for practical exam to complete their course. Every year, 4 to 5 experiments on Detection of 21 cm Hydrogen Line using Horn Antenna, Faraday Rotation, Noise Fundamentals (Johnson Noise), Cosmic Ray Muon Detection, and Raman Spectroscopy, are conducted in RPL.

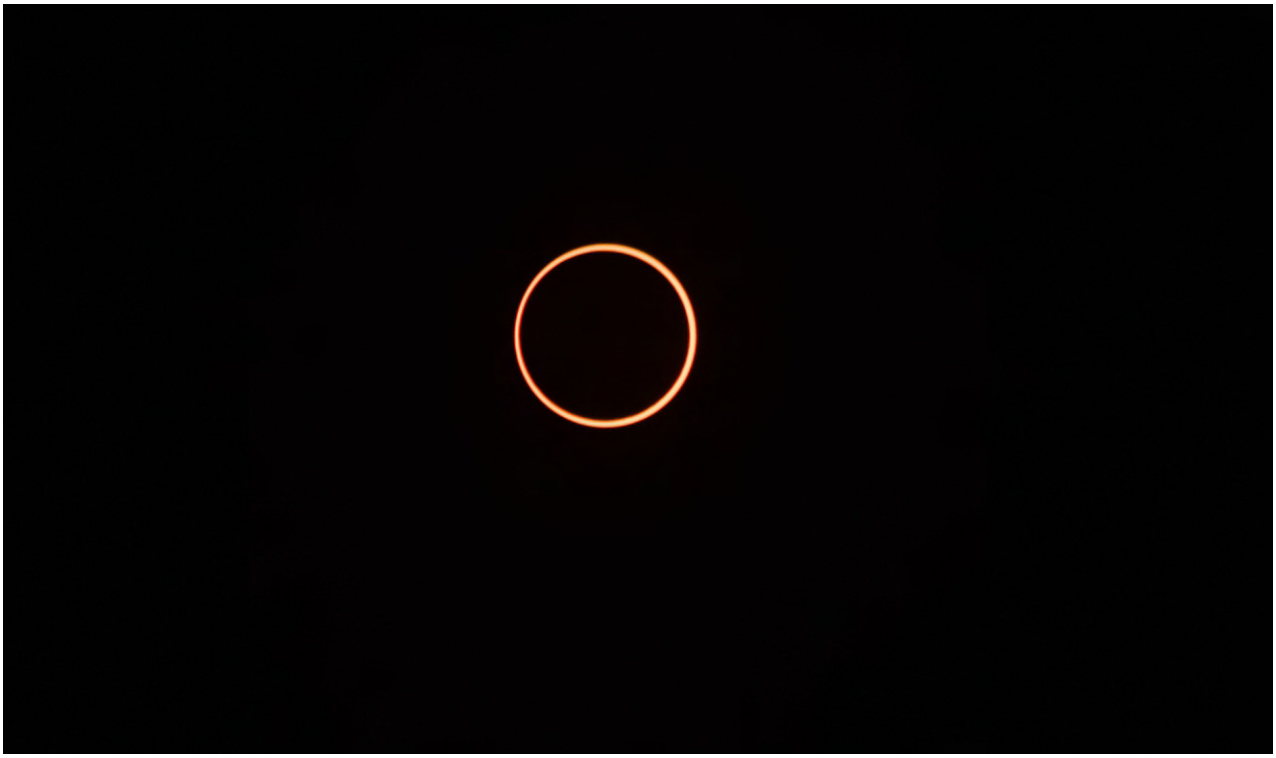
Lecture Series on Gravitational Lensing

RPL is interested to do some experiments on gravitational lensing, and design experiments to understand well and teach the under-graduate and post-graduate students. Hence, RPL requested Jean Surdej from Belgium, who is an expert in this field, to give a series of lectures. He happily agreed to visit IUCAA, and gave lectures on gravitational lensing. Along with Ranjan Gupta (IUCAA), RPL coordinated this lecture series and demonstration sessions. We thank Jean Surdej for the wonderful sessions.

Annular Solar Eclipse Observations

In December 2019, the Annular Solar Eclipse was observed from the southern part of India. The teams from IUCAA went to different parts of south India, and the RPL team was at Kannur in Kerala, where the annular eclipse belt was passing. We carried out some experiments in optical and radio, along with temperature variation during the eclipse. Using ASRT, we observed eclipse at around 11 GHz, and using Horn feed, we observed at 1420 MHz in radio domain. We also got really beautiful images of the annularity





SPONSORED MEETINGS AND EVENTS OUTSIDE IUCAA

Advanced B.Sc. (Physics) Summer Programme - 2019

The Advanced B.Sc. (Physics) Summer Programme was started by the joint efforts of the Gujarat Science Academy, and Vikram A. Sarabhai Community Science Centre (VASCSC), Ahmedabad in 2003, under the guidance of experts from Institute for Plasma Research (IPR), Physical Research Laboratory (PRL), Indian Space Research Organization (ISRO), etc. This year, it was conducted during May 11 - June 1, 2019, at St. Xavier's College (Autonomous), Ahmedabad, with the support from IUCAA, under the IUCAA Centre for Astronomy Research and Development (ICARD). The valedictory function was conducted at the Institute for Advanced Research (IAR), Gandhinagar, and Gurudatt Gaur (IAR) was the coordinator of the programme.

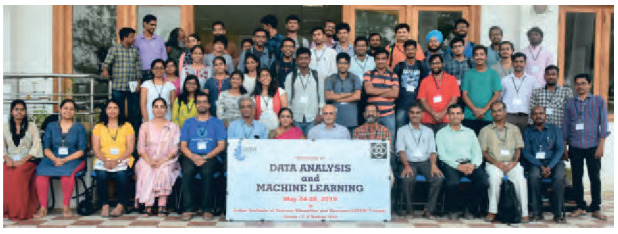
(For details, see KHAGOL No. 119 July 2019)



Workshop on Data Analysis and Machine Learning

Data science is now recognized as a new discipline, that deals with the acquisition, storage, retrieval, processing, and analysis of data. Around 50 participants of PhD students, post-doctoral fellows, post-graduate, and advanced under-graduate students from institutes, universities and colleges in India attended this workshop, which was conducted during May 24 - 28, 2019, at IISER, Tirupati and was coordinated by G. Ambika, and Arunima Banerjee (both from IISER, Tirupati), and Ranjeev Misra (IUCAA).

(For details, see KHAGOL No. 119 July 2019)



Astronomy Congress - 2019

The IUCAA Centre for Astronomy Research and Development (ICARD) initiated its activities in the Department of Physics, University of Calicut, Kozhikode, by joining hands with the Kerala Sastra Sahitya Parishad, to conduct the Astronomy Congress - 2019, during April 27-28, to commemorate the 50th anniversary of first landing on the Moon. Ravikumar C.D. was the coordinator of the congress.

(For details, see KHAGOL No. 119 July 2019)



North-East Meet of Astronomers 2019 (NEMA-V)

North-East Meet of Astronomers is an annual meeting of astronomers in the North-Eastern part of India, which was initiated in 2015 by the Department of Physics, Tezpur University and sponsored by IUCAA. This meeting aims to bring together young and highly motivated students, researchers, college and university teachers of the region, working or intending to take up research in the field of Astronomy and Astrophysics and related topics, on a single platform to stimulate discussions and collaborations.

The Department of Physics, Tezpur University organised the 5th edition of "North-East Meet of Astronomers-2019 (NEMA-V)", during September 11-13, 2019. This Workshop was coordinated by Rupjyoti Gogoi and Ranjeev Misra.

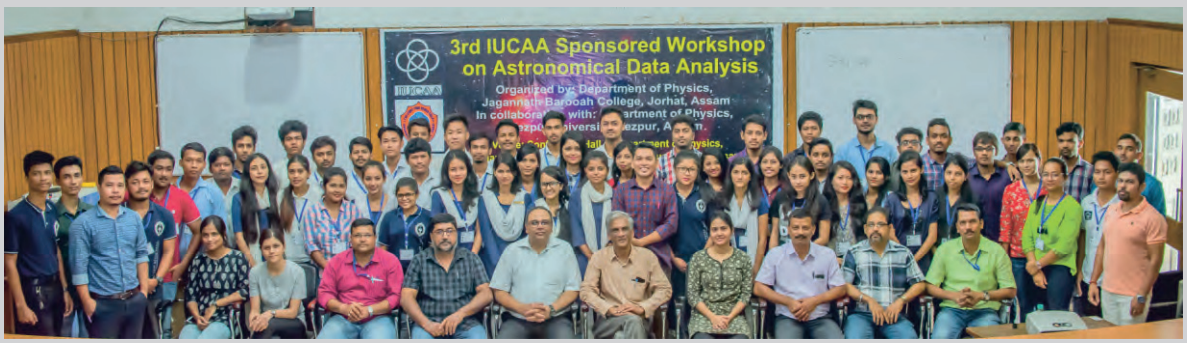
(For details, see KHAGOL No. 120 October 2019)



Workshop on Astronomical Data Analysis

The Department of Physics, Jagannath Barooah College (Autonomous), Jorhat, Assam, successfully organized the Third Workshop on Astronomical Data Analysis (WADA - 2019), during September 17 - 19, 2019, in association with Department of Physics, Tezpur University, Assam. The workshop was a part of IUCAA Centre for Astronomy Research and Development (ICARD) activity The coordinators of the workshop were Ranjeev Misra, Gazi A. Ahmed, and Ankur Gogoi (Jagannath Barooah College, Jorhat).

(For details, see KHAGOL No. 120 October 2019)



Workshop on Engineering Applications in Astronomy

A workshop on Engineering Applications in Astronomy was organized by IUCAA in collaboration with Vishwakarma Institute of Technology (VIT), Pune during August 19- 24, 2019 at VIT campus, Pune. The workshop was partially sponsored through a grant from Infosys Foundation to IUCAA.

(For details, see KHAGOL No. 120 October 2019)



Workshop on General Relativity and Cosmology

The Department of Mathematics, Institute of Applied Sciences and Humanities, GLA University, Mathura, in collaboration with IUCAA, organized the Workshop on General Relativity and Cosmology, during October 11 – 13, 2019. There were 41 participants, including 25 research scholars and 10 MSc students of physics and mathematics from all over the country, and 6 faculty members from GLA University. The workshop was coordinated by Aseem Paranjape (IUCAA) and Anirudh Pradhan (GLA University).

(For details, see KHAGOL No. 121 January 2020).



Workshop on Emergent Gravity Paradigm

The Workshop on Emergent Gravity Paradigm was held at the Department of Physics, Cochin University of Science and Technology (CUSAT), Kochi, during November 8 – 10, 2019. The focus was the theoretical foundations of gravity as an emergent phenomenon. Students and faculties from various institutions across India participated in this three-day residential workshop, which was organized by ICARD – CUSAT, and was coordinated by Aseem Paranjape (IUCAA), Titus K. Mathew, and Charles Jose (CUSAT).

(For details, see KHAGOL No. 121 January 2020).



Workshop on Statistical Applications in Astronomy and Astrophysics

The Workshop on Statistical Applications in Astronomy and Astrophysics, funded by IUCAA, and with academic support from the IUCAA Centre for Astronomy Research and Development, at the University of Calcutta, Kolkata, was conducted at the Department of Statistics, Assam University, Silchar, during November 20 - 22, 2019. The coordinators of the workshop were Asis Chattopadhyay (University of Calcutta), and Dibyojyoti Bhattacharjee.

(For details, see KHAGOL No. 121 January 2020).

National Workshop on AstroSat Data Analysis

The National Workshop on AstroSat Data Analysis was organized by the Department of Electronics, Goa University, in association with IUCAA, during November 20 - 22, 2019 at the Goa University. The coordinators of the workshop were Rajendra Gad (Department of Electronics, Goa University), Reshma Raut Desai, Ranjeev Misra, and Jayashree Roy.

(For details, see KHAGOL No. 121 January 2020).

Short-Term Course on Gravitation and Cosmology



A Short-Term Course on Gravitation and Cosmology was organized at the Department of Physics, Providence Women's College, Kozhikode, by the Teaching Learning Centre (TLC) of IUCAA for the benefit of teachers from their neighbouring colleges and universities, during November 25 - 30, 2019. The short-term course was coordinated by Jeena Karunakaran (Providence Women's College), and Surhud More (IUCAA).

(For details, see KHAGOL No. 121 January 2020).



Introductory Workshop on Physical Perspectives of Astronomy

The Department of Physics, ICFAI University, Tripura, jointly with the Department of Physics, Tripura University, Suryamaninagar, organized the Introductory Workshop on Physical Perspectives of Astronomy, during October 30 - 31, 2019. This workshop was a grand success, and there were a lot of interactions and discussions with the resource persons and the participants. Biplob Sarkar, and Gulab Chand Dewangan (IUCAA) were the coordinators of the workshop.

(For details, see KHAGOL No. 121 January 2020).

National Seminar on Applications of Statistics in Natural Sciences

The National Seminar on Applications of Statistics in Natural Sciences was held at St. Xavier's College, Kolkata, and was jointly organized by the Departments of Statistics and Physics, University of Calcutta, Kolkata, in collaboration with the IUCAA Centre for Astronomy Research and Development (ICARD), Kolkata, during December 16 - 17, 2019. Durba Bhattacharya (St. Xavier's College) was the coordinator.

(For details, see KHAGOL No. 121 January 2020).

International Workshop on LIGO-India

The School of Physical Sciences, Swami Ramanand Teerth Marathwada University (SRTMU), Nanded, Maharashtra, conducted the International Workshop on LIGO-India (IWLI-2019), during December 15-16, 2019, and was jointly organized by IUCAA; Indian Space Research Organization (ISRO), Bengaluru; and SRTMU.



The sessions were led by Udhav Bhosle, Ajit Kembhavi, Frederick Raab, L. M. Waghmare, and others. All the faculty members, administrative staff and students of the School of Physical Sciences, SRTMU, have taken much efforts in organizing this workshop. Sukanta Bose, and M. K. Patil were the coordinators of the workshop.

(For details, see KHAGOL No. 121 January 2020).

Workshop on Concepts in Astrophysics

The Department of Physics, Mar Thoma College, Chungathara, Nilambur, Kerala, in collaboration with IUCAA, organized the Workshop on Concepts in Astrophysics, during November 26 -27, 2019. This session was led by A.N. Ramaprakash, and 76 students from 6 different schools nearby Chungathara actively participated in the programme. The workshop was coordinated by A. N. Ramaprakash and Sheelu Abraham (Mar Thoma College, Chungathara).

(For details, see KHAGOL No. 121 January 2020).



Workshop on Science of the Star in our Backyard: Introduction and Data Analysis

Utilising the Annular Solar Eclipse 2019 as an excellent occasion to popularise Astronomy among the public and to educate science students about the Sun, IUCAA in collaboration with St. Mary's College, Sulthan Bathery, Kerala, has organised an eclipse viewing followed by the Workshop on Science of the Star in our Backyard: Introduction and Data Analysis, during December 26-29, 2019. The programme was coordinated by Durgesh Tripathi, and Joe Jacob.

(For details, see KHAGOL No. 121 January 2020).





Indian Association of Physics Teachers - Under-Graduates Camp in Physics and Astronomy

BITS-Pilani, K.K. Birla Goa Campus organized a Winter Camp in Physics and Astronomy, during December 19 – 22, 2019. Special thanks were to Somak Raychaudhury (Director, IUCAA), who supported the idea of using NGPE merit list as a means to identify meritorious under-graduate students from all over India. The coordinators were Dipankar Bhattacharya, and Arun V. Kulkarni.

(For details, see KHAGOL No. 121 January 2020).

Workshop on Astrophysics and Astronomy for Women in India

A two-day workshop on Astrophysics and Astronomy for Women in India sponsored by IUCAA, was jointly organised by the Department of Physics, Diamond Harbour Women University (DHWU), West Bengal and ICARD, North Bengal University (NBU) during January 31 - February 1, 2020 at the DHWU campus at Sarisha, 24 Parganas, West Bengal. B. C. Paul (NBU) and Ranjeev Misra (IUCAA) coordinated the workshop.

(For details, see KHAGOL No. 122 April 2020).



Seminar on X-ray Astronomy

A two-day national seminar on X-ray Astronomy was conducted during February 1-2, 2020, by the Department of Physics, St. Thomas College, Ranni, Kerala. Ranjeev Misra and Marykutty James were the co-ordinators of the seminar.

(For details, see KHAGOL No. 122 April 2020).



The IUCAA-CUTN School on Introductory General Relativity and Cosmology

The IUCAA-CUTN School on Introductory General Relativity and Cosmology was conducted at the Central University of Tamil Nadu (CUTN), Thiruvarur during January 4 - 11, 2020. T. R. Seshadri, V. Madhurima (CUTN) and Ranjeev Misra (IUCAA) coordinated the event.

(For details, see KHAGOL No. 122 April 2020).



International conference and school on The First Billion Years of the Universe using Next-Generation Telescopes

An international conference and school titled 'The First Billion Years of the Universe using Next-Generation Telescopes' was organized by one of the IUCAA Centres for Astronomy Research and Development (ICARD), The Discipline of Astronomy, Astrophysics and Space Engineering (DAASE), Indian Institute of Technology Indore at its campus in Indore during January 20-31, 2020.

(For details, see KHAGOL No. 122 April 2020).

RESEARCH BY VISITING ASSOCIATES

RESEARCH BY VISITING ASSOCIATES

Sheelu Abraham

Application of convolutional neural networks for stellar spectral classification

Due to the ever-expanding volume of observed spectroscopic data from surveys such as SDSS and LAMOST, it has become important to apply artificial intelligence (AI) techniques for analysing stellar spectra to solve spectral classification and regression problems like the determination of stellar atmospheric parameters $T_{\rm eff}$, logg, and [Fe/H]. We propose an automated approach for the classification of stellar spectra in the optical region using Convolutional Neural Networks. Traditional machine learning (ML) methods with "shallow" architecture (usually up to 2 hidden layers) have been trained for these purposes in the past. However, deep learning methods with a larger number of hidden layers allow the use of finer details in the spectrum which results in improved accuracy and better generalisation. Studying finer spectral signatures also enables us to determine accurate differential stellar parameters and find rare objects. We examine various machine and deep learning algorithms like Artificial Neural Networks (ANN), Random Forest (RF), and Convolutional Neural Network (CNN) to classify stellar spectra using the Jacoby Atlas, ELODIE and MILES spectral libraries as training samples. We test the performance of the trained networks on the Indo-U.S. Library of Coudé Feed Stellar Spectra (CFLIB). We show that using convolutional neural networks, we are able to lower the error up to 1.23 spectral sub-classes as compared to that of 2 sub-classes achieved in the past studies with ML approach. We further apply the trained model to classify stellar spectra retrieved from the SDSS database with SNR>20. This work has been done in collaboration with Kaushal Sharma, Ajit Kembhavi, Anirudha Kembhavi, T. Sivarani and Kaustubh Vaghmare.

Detecting outliers in SDSS using convolutional neural network

We propose an automated algorithm based on Convolutional Neural Network (CNN) for the detection of peculiar objects in large databases using their spectral observations. A convolutional neural network is a class of deep-learning algorithms which allows the detection of significant features/patterns in sequential data like images, audio, time-series etc. by applying convolutional neurons (kernels) along the sequence. For detecting unusual spectra, we use eight-layer deep convolutional network with autoencoder architecture on $\sim$ 60,000 spectra collected from **the** Sloan Digital Sky Survey. The training of the network is done in an unsupervised manner. We show that **the** trained network is able to retrieve the spectra of rare objects from a large collection of spectra. Such algorithms can easily be rescaled to other surveys and therefore can serve as a potential component of the data reduction pipelines for automatically detecting spectra with unusual features and recovering defective spectra. This work has been done in collaboration with Kaushal Sharma, Ajit Kembhavi, Anirudha Kembhavi, T. Sivarani

Dharam Vir Ahluwalia

Elko under spatial rotation

Under a rotation by an angle ϑ, both the right- and left- handed, Weyl spinors pick up a phase factor $exp(\pm i\vartheta/2)$. The upper sign holds for the positive helicity spinors, while the lower sign for the negative helicity spinors. For $\vartheta 2\pi$ radians this produces the famous minus sign. However, the four-component spinors are built from a direct sum of the indicated two-component spinors. The effect of the rotation by $\theta = 2\pi$ radians on the eigenspinors of the parity - that is, the Dirac spinors – is the same as on Weyl spinors. It is because for these spinors the right- and left- transforming components have the same helicity and the rotation induced phases, being same, factor out. But for the eigenspinors of the charge conjugation operator, i.e., Elko, the left- and right- transforming components have opposite helicities, and therefore, they pick up opposite phases. As a consequence, the behaviour of the eigenspinors of the charge conjugation operator (Elko) is more subtle: for $0 < \vartheta < 2\pi$, a self conjugate spinor becomes a linear combination of the self and antiself conjugate spinors with θ dependent superposition coefficients - and yet the rotation preserves the self/antiself conjugacy of these spinors! This apparently paradoxical situation is fully resolved. This new effect, to the best of our knowledge, has never been reported before. The purpose of this communication is to present this result and to correct an interpre-

tational error of a previous version. This work has been done in collaboration with Sweta Sarmah.

Magnetic field creation by solar mass neutrino jets

Parity violation and its effects for neutrinos in astrophysical contexts have been considered earlier in pioneering papers of Hawking and Vilenkin. But because even the largest magnetic moments predicted by physics beyond the Standard Model are some twelve orders of magnitude smaller than the Bohr magneton, their implications for magnetic field generation and neutrino oscillations are generally considered insignificant. Here, we show that since in astrophysical scenarios a huge number of neutrinos may be emitted, the smallness of the magnetic moment, when coupled with parity violation, is compensated by the sheer number of neutrinos. The merger of neutron stars would leave behind a short pulse of electromagnetic synchrotron radiation even if the neutrino jet in the merger points away from the neutrino detectors. We show that the magnetic field can be as large as 10^6 Gauss and comment on the possibility of direct detection. Observation of such a pulse would lend strong support for neutrino magnetic moments and resolve the missing neutrino problem in neutron star mergers. This work has been done in collaboration with Cheng-Yang Lee.

G. Ambika

Classification of close binary stars using recurrence networks.

In close binary stars, the component stars are close enough such that they can exchange mass and/or energy. They are subdivided into semi-detached, overcontact or ellipsoidal binary stars. A challenging problem in the context of close binary stars is their classification into these subclasses, based solely on their light curves. Conventionally, this is done by observing subtle features in the light curves like the depths of adjacent minima, which is tedious when dealing with large datasets. In this work, we suggest the use of machine learning algorithms applied to measures of recurrence networks and nonlinear time series analysis to differentiate between classes of close binary stars. We show that overcontact binary stars occupy a region different from semi-detached and ellipsoidal binary stars in a plane of characteristic path length (CPL) and average clustering coefficient (CC), computed from their recurrence networks. We use standard clustering algorithms and report that the clusters formed correspond to the standard classes with a high degree of accuracy. This work has been in collabration with Sandip V. George, and Ranjeev Misra.

Synapse loss and progress of Alzheimer's disease - A network model.

We present observational evidence from studies on primary cortical cultures from AD transgenic mice, APPSwe/PS1ΔE9 (APP/PS1) mice, for significant decrease in total spine density at DIV-15 and onward. This indicates reduction in potential healthy synapses and strength of connections among neurons. Based on this, a network model of neurons is developed, that explains the consequent loss of coordinated activity and transmission efficiency among neurons that manifests over time. The critical time when structural connectivity in the brain undergoes a phase-transition, from initial robustness to irreparable breakdown, is estimated from this model. We also show how the global efficiency of signal transmission in the network decreases over time. Moreover, the number of multiple paths of high efficiency decreases rapidly as the disease progresses, indicating loss of structural plasticity and inefficiency in choosing alternate paths or desired paths for any pattern of activity. Thus, loss of spines caused by β -Amyloid (Aβ) peptide results in disintegration of the neuronal network over time with consequent cognitive dysfunctions in Alzheimers Disease (AD). This work has been done in collaboration with G. Srikanth Kashyap, Deepti Bapat, D. Das, Ruturaj Gowaikar, Ravindra E. Amritkar, et al.

Arunima Banerjee

The specific angular momenta of superthin galaxies: Cue to their origin?

Superthin galaxies are low surface brightness (LSB) bulgeless disc galaxies having stellar discs with unusually high planar-to-vertical axes ratio $b/a > 10$ - 20, the formation and evolution of which is not well-understood. We calculate the specific angular momenta of a sample of six superthins and nine other bulgeless LSBs using stellar photometry, atomic hydrogen (HI) surface density and high resolution HI rotation curves available in the literature. We find that the stellar specific angu-

lar mometum $j_{\rm s}$, and hence, the stellar disc size given by the exponential stellar disc scale length R_D, of three superthins and seven LSBs lie above the 95.4 % confidence band of the $j_{\rm s}$ - $V_{\rm rot}$ regression line for ordinary bulgeless disc galaxies, $V_{\rm rot}$ being the asymptotic rotational velocity. Further, we find that superthins and LSBs have higher $j_{\rm s}$ and R_D values for a given value of stellar mass $M_{\rm s}$ at high values of statistical significance, compared to ordinary disc galaxies. Therefore, we conclude, a superthin may be distinguished by a characteristically larger disc size, which could possibly explain the origin of its large planar-to-vertical axes ratio. Interestingly, we find that the median spin parameter is 0.13 ± 0.01 for superthin galaxies, which is an order of magnitude higher than those of LSBs and ordinary disc galaxies, which may have important implications for the existence of superthin stellar discs in these low surface brightness galaxies. This work has been done in collaboration with Vikas Jadhav Y.

Sarmistha Banik

Properties of massive rotating protoneutron stars with hyperons: Evolution and universality

In this work, we study the properties and structure of a massive and rapidly rotating protoneutron star (PNS) with hyperon content. We follow several stages of quasi-stationary evolution in an approximate way at four discrete steps. We use a density-dependent (DD) relativistic mean field theory (RMF) model and calculate different quantities such as mass, equatorial radius, moment of inertia, and quadrupole moment to get different rotating configurations upto the mass-shedding limit. We study the effect of the appearance of Λ, the lightest of all hyperons, on each of the evolutionary stages of the PNS. We also check its sensitivity to the inclusion of ϕ vector meson as a mediator of $\Lambda - \Lambda$ interaction in detail. Finally, we investigate the universal relations between moment of inertia and compactness in the context of a hot and young compact object. This work has been done in collaboration with Smruti S. Lenka, and Prasanta Char.

Signatures of strangeness in neutron star merger remnants

Neutron star (NS) mergers provide us with information rich in physics using multi-messenger astrophysical observations. One of the probable remnants of such a merger is a differentially rotating hot hypermassive neutron star. The stability of the merger remnant depends crucially on the underlying Equation of State (EoS) and thus, provides a method to probe the nature of dense matter in NSs. In this work, we search for possible signatures of strangeness containing matter in the NS interior on the secular stability of the merger remnant. We also use recently proposed methods to make a rough estimate the collapse time of the merger remnant and the threshold mass above which the merger promptly collapses to a black hole. This work has been done in collaboration with Krishna Prakash Nunna, and Debarati Chatterjee.

Aru Beri

The black hole X-ray transient Swift J1357.2-0933 as seen with Swift and NuSTAR during its 2017 outburst

One of our recent works involves a multi-wavelength approach to study an enigmatic X-ray binary, Swift J1357.2-0933. This work was also part of the SmartNet, which is the Simultaneous Multiwavelength Astronomy Research in Transients Network, which involves group of researchers all accross the globe. Multiwavelength observations are vital to understand the comprehensive picture of an X-ray binary. We report on observations of black hole Swift J1357.2-0933, a member of the modest population of very faint X-ray transients. This source has previously shown intense dips in the optical lightcurve, a phenomena that has been linked to the existence of aunique toroidal structure in the inner region of the disc, seen at a high inclination. Our observations, carried out by the Neil Gehrels Swift and NuSTAR X-ray observatories, do not show the presence of intense dips in the optical light curves. We find that the X-ray light curves do not show any features that would straightforwardly support an edge-on configuration or high inclination configuration of the orbit. This is similar to what was seen in the X-ray observations of the source during its 2011 outburst. Moreover, the broadband spectra were well described with an absorbed power-law model without any signatures of cut-off at energies above 10 keV, or any reflection from the disc or the putative torus. Thus, the X-ray data do not support the unique obscuring torus scenario proposed for J1357. We also performed a multi-wavelength study using the data of X-ray

telescope and Ultraviolet/Optical Telescope aboard Swift, taken during the 4.5 months duration of the 2017 outburst. This is consistent with what was previously inferred for this source. We found a correlation between the simultaneous X-ray and ultraviolet/optical data and our study suggests that most of the reprocessed flux must be coming out in the ultraviolet. This work has been done in collaboration with Bailey E. Tetarenko, Arash Bahramian, Diego Altamirano, Poshak Gandhi, et al.

A broadband look of the accreting millisecond X-ray pulsar SAX J1748.9-2021 using AstroSat and XMM-Newton

X-ray pulsars exhibit strict periodic variations in X-ray intensity. In some neutron stars (NS), X-ray pulsations of the order of millisecond have been detected (see e.g., Chakrabarty & Morgan 1998). They belong to peculiar type of X-ray pulsars called accretion powered millisecond X-ray pulsars (AMXPs). The short spin periods are caused by long-lasting mass transfer from a low-mass companion star through an accretion disc onto a rotating neutron star. AMXPs are perceived by the scientific community as astrophysical laboratories that could be essential to our understanding of thermonuclear burst processes. So far, only 22 such AMXPs have been detected. We have analyzed and studied one of these sources SAX J1748.9-2021 using 200 kiloseconds (ks) long observation made with Indias first multi-wavelength satellite AstroSat, and 60 ks long observation made with XMM-Newton launched by Europeon Space Agency (ESA). SAX J1748.9-2021 is a transient AMXP, located in the globular cluster NGC 6440. We report on the spectral and timing analysis of SAX J1748.9-2021 performed on AstroSat data taken during its faint and short outburst of 2017. We derived the best-fitting orbital solution for the 2017 outburst and obtained an average local spin frequency of 442.361098(3) Hz. The pulse profile obtained from 3-7 keV and 7-20 keV energy bands suggest constant fractional amplitude 0.5% for fundamental component, contrary to previously observed energy pulse profile dependence. The AstroSat observations revealed the source to be in a hard spectral state. The 1-50 keV spectrum from SXT and LAXPC on-board AstroSat can be well described with a single temperature blackbody and thermal Comptonization. Moreover, we found that the combined spectra from XMM-Newton (EPIC-PN) and AstroSat (SXT+LAXPC) indicated the presence of reflection features in the form of iron (Fe K_α) line that we modelled with the reflection model xillvercp. One of the two X-ray bursts observed during the AstroSat/LAXPC observation showed hard X-ray emission ($>$ 30 keV) due to Compton up-scattering of thermal photons by the hot corona. Time resolved analysis performed on the bursts revealed complex evolution in emission radius of blackbody for second burst suggestive of mild photospheric radius expansion. This work has been done in collaboration with Rahul Sharma, Andrea Sanna, and Anjan Dutta.

Piyali Bhar

Compact star in Tolman-Kuchowicz spacetime in the background of Einstein-Gauss-Bonnet gravity

The present work is devoted to the study of anisotropic compact matter distributions within the framework of five-dimensional Einstein-Gauss-Bonnet gravity. To solve the field equations, we have considered that the inner geometry is described by Tolman-Kuchowicz spacetime. The Gauss-Bonnet Lagrangian, L_{GB} is coupled to the Einstein-Hilbert action through a coupling constant, namely α. When this coupling tends to zero, general relativity results are recovered. We analyze the effect of this parameter on the principal salient features of the model, such as energy density, radial and tangential pressure and anisotropy factor. These effects are contrasted with the corresponding general relativity results. Besides, we have checked the incidence on an important mechanism: equilibrium by means of a generalized Tolman-Oppenheimer-Volkoff equation and stability through relativistic adiabatic index and Abreus criterion. Additionally, the behaviour of the subliminal sound speeds of the pressure waves in the principal directions of the configuration and the conduct of the energy-momentum tensor throughout the star are analyzed employing the causality condition and energy conditions, respectively. All these subjects are illuminated by means of physical, mathematical and graphical surveys. The M-I and the M-R graphs imply that the stiffness of the equation of state increases with α; however, it is less stiff than GR.This work has been done in collaboration with Ksh. Newton Singh, and Francisco Tello-Ortiz.

Charged compact star model in Einstein-Maxwell-Gauss-Bonnet gravity

In this work, we present a model of a static charged anisotropic fluid sphere in the Einstein-Maxwell-Gauss-Bonnet (EMGB) theory of gravitation. We utilize the Krori-Barua (KB) ansatz together with a linear equation of state of the form $p_r = \beta\rho - \gamma$ to generate exact solutions of the EMGB field equations describing compact objects. The model obtained here is found to satisfy the elementary physical requirements necessary for a physically realizable stellar object. We demonstrate that contributions from the Gauss-Bonnet terms have a non-zero impact on the density, pressure and anisotropy profiles. The vanishing of the electromagnetic field at the centre of the stellar configuration leads to a relation between the equation of state parameter and the Gauss-Bonnet term. Our model reveals a direct connection between the nature of the matter configuration and higher dimensional effects. This work has been done in collaboration with Megan Govender.

Naseer Iqbal Bhat

Thermodynamics and phase transitions in galaxy clustering

The phenomenon of galaxy clustering has been studied from the perspective of the gravitational phase transition, which is somewhat different from a phase transition in material science. There is evidence that the phase transition describing galaxy clustering in an expanding universe is a first order phase transition exhibiting a mixed phase. As such, the Clausius Clapeyron equation is relevant for studying such a system. In this work, we derive a general analogue of the Clausius Clapeyron equation that applies not only towards the coexistence curve in pressure-temperature space, but to a more general parameter space. The key finding is that a cusp exists at the critical point in this mixed phase when viewed in this more general parameter space. We extend this formalism to derive an equation for the curvature of the phase coexistence curve in pressure-temperature space and a more general parameter space. We also verify previous findings of hysteresis in the system via an independent free energy analysis. This work has been done in collaboration with Nasser Demir.

Ritabrata Biswas

Search for missing links between two extreme wind speed profiles: Dark energy accretion and adiabatic fluid accretion

In recent past, the progresses in accretion studies onto relativistically gravitating central objects like a Schwarzschild singularity reveal that the accretion flow must be transonic. For such cases, the radial inward speed gradient can be written as a numerator by denominator form, among which the later vanishes somewhere in between infinite distance from the attracter to the event horizon of the same. For sustainability of a physical solution, the numerator should vanish at the same radial distance where denominator does vanish. From this point, we obtain a second degree first order differential equation of radial inward speed and hence, we obtain two branches of flow, namely accretion and wind. For adiabatic accretion case, the wind curve is formed to be more or less parallel to the radial distance axis as we move far from the central object. For dark energy accretion, this curve is parallel to the radial velocity axis. Here we face a question: Why there is no fluid speed profiles in between these two extremities? While searching the reasons, we follow that dark energy, if treated as an accreting object, should stay around the central compact star and hence, will contaminate the metric which propertises the compact star. In this research work, we have proposed a model with a rotating black hole embedded in quintessence, where quintessence equation of state and spin parameters of the black hole are regulatory factors of the model. The resulting accretion and wind curves are studied. The effect of negative pressure of dark energy is found to get catalyzed by the entry of the spin of the black hole. We tally our results with observations of accretion or outflow phenomenon near to different quasars. This work has been done in collaboration with Parthajit Roy.

Threshold drop in accretion density if dark energy is accreting onto a supermassive black hole

Recent studies of galactic cores tell us that supermassive black holes are hosted at each of these cores. We got some evidences even. Besides, dark energy is expected to be distributed all over in our universe. Dark matter halo, on the other hand, could be found around the galactic regions. Though the natures of spans of them are not clearly

measured, galactic structures are supposed to be formed out of dark matter clustering. Some examples of supermassive black holes in the central regions of high redshift galaxies say that the concerned supermassive black holes have completed their constructions in a time less than it generally should be. To justify such discrepancies, we are forced to model about existences of black hole mimickers and exotic phenomena acting near the supermassive black holes. Motivated by these, we study the natures of exotic matters, especially dark energy near the black holes. We choose modified Chaplygin gas as dark energy candidate. Again, the descriptions of gravitational waves or the attenuations of them when they are tunnelling through cosmological distances help us to measure the shear viscosity of the medium through which the waves have been travelled. Delayed decaying models of dark matters also suggest that dark energy and viscosity may come up as a byproduct of such decays or interactions. We consider the viscous nature of the medium, i.e., the dark energy. To do so, we choose an alpha-disc model as proposed by Shakura and Sunyaev. We study the variations of densities through accretion and wind branches for a different amount of viscosity regulated by the Shakura-Sunyaev alpha parameter, spin parameter and different properties of accreting fluids, viz, the properties of adiabatic fluid and modified Chaplygin gas. We compare these results with each other and some existing density profiles drawn from observational data-based simulations. We follow that the result supports the data observed till date. Specifically, we see the wind to get stronger for dark energy as accreting agent. Besides, we see the accretion to have a threshold drop if the viscosity is chosen along with the repulsive effects of dark energy. This work has been done in collaboration with Sandip Dutta.

Subenoy Chakraborty

Quantum cosmology for non-minimally coupled scalar field in FLRW spacetime: *A symmetry analysis*

The present work deals with quantum cosmology for non-minimally coupled scalar field in the background of FLRW spacetime model. The Wheeler-DeWitt equation is constructed and symmetry analysis is carried out. The Lie point symmetries are related to the conformal algebra of the minisuperspace while solution of the Wheeler-DeWitt equation is obtained using conserved currents of the Noether symmetries. This work has been done in collaboration with Sourav Dutta, and Muthusamy Lakshmanan.

Homogeneous and isotropic spacetime, modified torsion field and complete cosmic scenario

This work deals with cosmological solutions describing different phases of the Universe for the homogeneous and isotropic FLRW model with torsion. Normally, torsion field is not suitable for maximally symmetric spacetime model. However, one may use a specific profile of vectorial torsion field, derived from a scalar function. By proper choices of the torsion scalar function, it is shown that a continuous cosmic evolution starting from the emergent scenario to the present late time acceleration is possible. Also thermodynamics of the system is analyzed and equivalence with Einstein gravity is discussed. This work has been done in collaboration with Akash Bose.

Nand Kumar Chakradhari

Optical and UV studies of type Ia supernovae SN 2009ig and SN 2012cg

We present an extensive optical-ultraviolet photometry, and analysis of a series of optical spectra of type Ia supernovae SN 2009ig and SN 2012cg. The observations range from -15 to $+185$ d for SN 2009ig and -14 to 316 d for SN 2012cg, with respect to maximum light in B band. Both SN 2009ig, and SN 2012cg exhibit similar properties. They have similar decline rate parameter ($\Delta m_{15}(B)_{\rm true} = 0.92 \pm 0.04$ for SN 2009ig and 0.93 $\pm$ 0.06 for SN 2012cg) and B band peak absolute magnitude (-19.45 ± 0.40 mag for SN 2009ig and -19.50 ± 0.31 mag for SN 2012cg). Their early spectra show high velocity features in Si II and Ca II lines. The strong Fe III, Si III and weak Si II λ5972 line during pre-maximum phase are indicative of hot photosphere. The post-maximum velocity evolution shows a plateau like phase with velocities $\sim$ 13,000 km s^{-1} for SN 2009ig and $\sim$10,000 km s^{-1} for SN 2012cg. Both events show spectral evolution similar to normal SNe Ia and fall in LVG and Core Normal subgroup. Both have smaller strength ratio ($\mathcal{R}$(Si II) = 0.17 for SN 2009ig, and 0.20 for SN 2012cg) consistent with smaller $\Delta m_{15}(B)$. Peak bolometric luminosities ($\log L_{\rm bol}^{\rm max}$) of these events

are estimated as 43.17 ± 0.16 erg s^{-1}, and 43.24 ± 0.11 erg s^{-1} suggesting that 0.60 ± 0.20 M$_\odot$ of ^{56}Ni was synthesized in the explosion of SN 2009ig, and 0.72 ± 0.31 M$_\odot$ in SN 2012cg. This work was carried out in collaboration with Devendra K. Sahu, and G. C. Anupama.

Ground-based photometric survey to search for the pulsational variability in Bp, Ap, and Am stars

We present the analysis of time-series of photoelectric data of a Bp star and four new Ap stars observed photoelectrically under the Nainital-Cape survey programme. The project was started about two decades ago, aiming to search for new rapidly oscillating Ap stars. The frequency analysis of the time-series of these stars obtained on multiple nights did not reveal any pulsational variability. In addition to this, we have performed the analysis of time-series differential CCD photometry of the two pulsating Am stars HD 13038 and HD 13079, where we find some evidence of new periods. To expand and strengthen the ongoing survey work, we propose to build-up a tri-national collaboration of astronomers from India, South Africa and Belgium. This work was carried out in collaboration with Daniel Nhlapo, Santosh Joshi, Bruno Letarte, and Sanjeev Kumar Tiwari.

Ramesh Chandra

How rotating solar atmospheric jets become Kelvin-Helmholtz unstable ?

The Kelvin-Helmholtz instability (KHI) is a ubiquitous phenomenon across the Universe. Over the past two decades, several space missions have enabled our understanding of this phenomenon at the Sun's atmosphere. Key results obtained by Hinode and Atmospheric Imaging Assembly on board the Solar Dynamics Observatory allowed us to get useful data concerning the physical parameters of various solar jets and the characteristics of detected waves and instabilities in those structures. The rotating solar jets are among the most spectacular events in our Sun. They support the propagation of a number of magnetohydrodynamic (MHD) modes which, under some conditions, can become unstable and the developing instability is of the KH kind. In its non-linear stage, the KHI can trigger the occurrence of wave turbulence, which is considered as one of the basic mechanisms of the coronal heating. The modelling of tornado-like phenomena in solar chromosphere and corona as moving weakly twisted and spinning cylindrical flux tubes shows that the KHI rises at the excitation of high-mode MHD waves. The instability occurs within a wave number range/window whose width depends on the MHD mode number m, the plasma density contrast between the rotating jet and its environment, as well as on the twists of the internal magnetic field and jet's velocity. We have studied KHI instability in a twisted solar polar coronal hole jet, in a twisted rotating jet emerging from a filament eruption, and in a rotating macrospicule. It has been established that good agreement between the theoretically calculated KHI developing times of a few minutes at wavelengths comparable to the half-widths of the jets, and those growth times detected from observations can be achieved at the excitation of high ($9 \leq m \leq 52$) MHD modes only. This work has been done in collaboration with Ivan Zhelyazkov, and Reetika Joshi.

Kinematics and energetics of the EUV waves on 11 April, 2013

In this study, we present the observations of extreme-ultraviolet (EUV) waves associated with an M6.5 flare on 11 April 2013. The event was observed by Solar Dynamics Observatory (SDO) in different EUV channels. The flare was also associated with a halo CME and type II radio bursts. We observed both fast and slow components of the EUV wave. The speed of the fast component, which is identified as a fast-mode MHD wave, varies in the range from 600 to 640 km/s, whereas the speed of the slow-component is $\approx$ 140 km/s. We observed the unusual phenomenon that, as the fast-component EUV wave passes through two successive magnetic quasi-separatrix layers (QSLs), two stationary wave fronts are formed locally. We propose that part of the outward-propagating fast-mode EUV wave is converted into slow-mode magnetohydrodynamic waves, which are trapped in local magnetic field structures, forming successive stationary fronts. Along the other direction, the fast-component EUV wave also creates oscillations in a coronal loop lying $\approx$ 225 Mm away from the flare site. We have computed the energy of the EUV wave to be of the order of 1020 J. This work was done in collaboration with Aarti Fulara, Peng Fei Chen, Ivan Zhelyazkov, Abhishek K. Srivastva, and W. Uddin.

Suresh Chandra

H_2SiO IRASERs in a warm region in interstellar medium

Out of the silicon bearing molecules, found in cosmic objects, the H_2SiO is one of them. Considering that kinetic temperature in some molecular regions is found up to 300 K, for each of the ortho and para H_2SiO, we have extended our investigation to 200 rotational levels having energy up to 540 cm^{-1}. Performing LVG calculations, we have found 5 ortho and 4 para transitions having frequencies in THz, and radiative life-time of upper level more than 10 times larger than that of the lower level. These transitions, may be called IRASERs (Infra-Red Amplification by Stimulated Emission of Radiation), having emission feature and may play important role in identification of H_2SiO in a warm region in the interstellar medium. This work has been done in collaboration with Mohit K. Sharma, and Monika Sharma.

Electron cyclotron waves in plasma in magnetosphere of a planet having perpendicular DC electric field

Scientists have always been interested in the study of electron cyclotron waves in plasma in magnetosphere of a planet. Series of papers are published, where AC electric field is taken perpendicular to magnetic field in the magnetosphere. Some scientists have claimed to consider DC electric field, but they are found not to have any electric field. We have discussed propagation of electron cyclotron waves when constant electric field is perpendicular to magnetic field in megnetosphere of a planet. Using bi-Maxwellian distribution function, we have found that for the known value of electron cyclotron frequency ω_c, the real oscillation frequency ω_r depends only on the temperature anisotropy. We have also found that the growth rate γ increases continuously with the increase of the wavevector k. It is interesting to note that the dispersion relation used in series of papers is erroneous, and it has been taken as universal relation. This studey has been done in collaboration with Mohit K. Sharma.

Ayan Chatterjee

Effective quantum theory of black hole horizons

We develop an effective quantum theory of black hole horizons using only the local horizon geometry. On the covariant phase space of the Holst action admitting Weak Isolated Horizon as an inner boundary, we construct Hamiltonian charges corresponding to Lorentz symmetries. We show that horizon area is the Hamiltonian charge corresponding to Lorentz boosts as well as that for Lorentz rotation, which acts on 2-sphere cross-sections of the horizon. Using this expression of area as a generator of Lorentz rotation, and the fact that quantum states residing on the horizon cross-sections carry a representation of $ISO(2)$, we derive the spectrum of area operator on the horizon. The eigenstates of this area operator are shown to be labelled by integers or half integers. The entropy is obtained completely in terms of these *area quanta* residing on the horizon, and is shown to have exponentially suppressing corrections to the area law. The formalism is also extended to non-minimally coupled scalar fields, where the area operator gets modified due to the value of the scalar field on the horizon. This work has been done in collaboration with Amit Ghosh.

Marginally trapped surfaces in spherical gravitational collapse

This work deals with a detailed study of gravitational collapse of dust and viscous fluids under the assumptions of spherical symmetry. Our main goal is to closely analyze the horizons which arise during this gravitational phenomenon. To this end, we examine the formation and evolution of trapped surfaces in these spacetimes, with special attention to trapped regions and cylinders foliated by marginally trapped surfaces. The time evolution of trapped surfaces, collapsing shell as well as the event horizon are identified analytically as well as numerically. Using different density profiles of matter, we analyze, how the nature of the marginally trapped surfaces modify as we change the energy momentum tensor. These studies reveal that depending on the mass function and the mass profile, it is possible to envisage situations where dynamical horizons, timelike tubes or isolated horizons may arise. This work has been done in collaboration with Amit Ghosh, and Suresh Jaryal.

Ritaban Chatterjee

The accretion disk-jet connection in blazars

The power spectral density (PSD) of the X-ray emission variability from the accretion disk-corona

region of black hole X-ray binaries and active galactic nuclei has a broken power-law shape with a characteristic break timescale T_B. If the disk and the jet are connected, the jet variability may also contain a characteristic timescale related to that of the disk-corona. Recent observations of the blazar Mrk 421 have confirmed the broken power-law shape of the PSD of its jet X-ray variability. We model the time variability of a blazar, in which emitting particles are assumed to be accelerated by successive shock waves flowing down the jet with a varying inter-shock timescale (T_{IS}). We investigate the possible relation between the characteristic timescales in the disk and jet variability based on the above model, along with mathematically and physically simulated disk variability. We find that both the PSD of the jet and disk variability may have a broken power-law shape but the break timescales are not related in general except only in systems with a small range of BH mass. The break in the jet and disk PSD are connected to the interval between large amplitude outbursts in the jet (T_{IS}) and to the viscous timescale in the disk, respectively. In frequency bands where multiple emission processes are involved or emission is from lower energy particles, the break in the PSD may not be prominent enough for detection. This study has been done in collaboration with Sagnick Mukherjee, and Kaustav Mitra.

Physical inference from the γ-ray, X-ray and optical time variability of a large sample of Fermi blazars

We present cross-correlation studies of γ-ray (0.1-300 GeV), X-ray (0.2-10 keV) and optical (R-band) variability of a sample of 16 blazars during 2008-2016. The light curves are from the *Fermi*-LAT, *Swift-XRT*, and Yale-SMARTS blazar monitoring programme. We stack the discrete cross-correlation functions of the blazars such that the features that are consistently present in a large fraction of the sample become more prominent in the final result. We repeat the same analysis for two subgroups, namely, low synchrotron peaked (LSP) and high synchrotron peaked (HSP) blazars. We find that on average the variability at multiple bands is correlated with a time lag consistent with zero in both subgroups. We describe this correlation with a leptonic model of non-thermal emission from blazar jets. By comparing the model results with that from the actual data, we find that the inter-band cross-correlations are consistent with an emission region of size ~ 0.1 pc within the broad line region for LSP blazars. We rule out large changes of magnetic field (> 0.5 Gauss) across the emission region or small values of magnetic field (~ 0.2 Gauss) for this population. We also find that the observed variability of the HSP blazars can be explained if the emission region is much larger than the distance to the broad line region from the central black hole. This study has been done in collaboration with Anwesh Majumdar, Kaustav Mitra, C. M. Urry, C. D. Bailyn, and Prantic Nandi.

Suchetana Chatterjee, and Nishikanta Khandai

Cosmological simulation of galaxy groups and clusters. I. Global effect of feedback from active galactic nuclei

In this study, we quantify the properties of the gas and dark matter around active galactic nuclei (AGN) in simulated galaxy groups and clusters and analyze the effect of AGN feedback on the surrounding intra-cluster (group) medium. Our results suggest downsizing of AGN luminosity with host halo mass, supporting the results obtained from clustering studies of AGN. By examining the temperature and density distribution of the gas in the vicinity of AGN, we show that due to feedback from the central engine, the gas gets displaced from the centre of the group/cluster resulting in a reduction of the density but an enhancement of temperature. We show that these effects are pronounced at both high and low redshifts and propose new observables to study the effect of feedback in higher redshift galaxies. We also show that the average stellar mass is decreased in halos in the presence of AGN feedback confirming claims from previous studies. Our work for the first time uses a fully cosmological-hydrodynamic simulation to evaluate the global effects of AGN feedback on their host dark matter halos as well as galaxies at scales of galaxy groups and clusters. This work has been done in collaboration with Rudrani Kar Chowdhury, Anto Lonappan, and Tiziana Di Matteo .

Surajit Chattopadhyay

Cosmology of a generalized version of holographic dark energy in presence of bulk viscosity and its inflationary dynamics through slow roll parameters

In this work done jointly with Gargee Chakraborty, we aimed at reconstructing ρ_Λ through H in non-interacting and interacting scenario and holographic background evolution. The bulk viscous pressure has been taken as $\Pi = -3H\xi$, where $\xi = \xi_0 + \xi_1 H + \xi_2(\dot{H} + H^2)$. In the reconstruction scheme reported here, firstly we choose viscous scenario neglecting the contribution of dark matter and without any choice of scale-factor. A dark energy (DE) model with higher order derivative of Hubble parameter, which is a particular case of Nojiri-Odintsov holographic DE, that unifies phantom inflation with the acceleration of the universe on late-time. The reconstruction has been carried out in the presence of bulk-viscosity, where the bulk-viscous pressure has been taken as a function of Hubble parameter. Ranges of cosmic time t have been derived for quintessence, cosmological constant and phantom behaviour of the equation of state (EoS) parameter. In the viscous scenario, the reconstruction has been carried out in an interacting and non-interacting situations and in both the cases, stability against small perturbations has been observed. Finally, the slow roll parameters have been studied and a scope of exit from inflation, has been observed. Also, availability of quasi-exponential expansion has been demonstrated for interacting viscous scenario and a study through tensor to scalar ratio has ensured consistency of the model with the observational bound by Planck. Along with primordial fluctuations, the interacting scenario has been found to generate strong dissipative regime.

A study of the bulk viscous pressure in scalar fields and holographic ricci dark energy considered in the modified gravity framework

This work is rigorous study of the reconstruction of the modified gravity in the framework of the scalar field models of dark energy and holographic Ricci dark energy, a generalized version of the holographic dark energy presented in S. Nojiri and S. D. Odintsov [*Gen. Rel. Grav.* **38**, 1285 (2006)]. The tachyon and quintessence scalar fields have been considered and the cosmology associated with the presence of bulk viscosity has been studied. In the first part of the study, we have demonstrated the behaviuor of the bulk viscosity coefficient in the framework of the reconstructed tachyon scalar field model of dark energy. The scale factor is chosen in the form $a(t) = a_0 t^\beta$, where $\beta > 0$. Two scalar field models, namely, tachyon and quintessence have been considered in the framework of the modified field equations through incorporation of the bulk viscous pressure. The reconstructed density and pressure of the scalar field models have been explored for the cosmological consequences in the presence of bulk viscosity. The behaviour of the effective equation of state parameters has been investigated. Finally, we have reconstructed $f(T)$ gravity in the presence of holographic Ricci dark energy and a transition of the effective equation of state parameter from quintessence to phantom has been observed. This work has been carried out in collaboration with Sthiti Chakrabarti, and Irina Radinchi.

Bhag Chand Chauhan

Investigating the sterile neutrino parameters with QLC in 3 + 1 scenario

In the scenario with four generation quarks and leptons and using a 3 + 1 neutrino model having one sterile and the three standard active neutrinos with a 4×4 unitary transformation matrix, U_{PMNS_4}, we perform a model-based analysis using the latest global data and determine bounds on the sterile neutrino parameters, i.e., the neutrino mixing angles. Motivated by our previous results, where in a quark-lepton complementarity (QLC) model, we predicted the values of $\theta_{13}^{PMNS} = (9^{+1}_{-2})^\circ$ and $\theta_{23}^{PMNS} = (40.60^{+0.1}_{-0.3})^\circ$. In the QLC model, the non-trivial correlation between CKM_4 and $PMNS_4$ mixing matrix is given by the correlation matrix V_{c_4}. Monte Carlo simulations are performed to estimate the texture of V_{c_4} followed by the calculation of $PMNS_4$ using the equation, $U_{PMNS_4} = (U_{CKM_4}.\psi_4)^{-1}.V_{c_4}$, where ψ_4 is a diagonal phase matrix. The sterile neutrino mixing angles, θ_{14}^{PMNS}, θ_{24}^{PMNS} and θ_{34}^{PMNS} are assumed to be freely varying between $(0 - \pi/4)$, and obtained results which are consistent with the data available from various experiments, like NoνA, MINOS, SuperK, Ice Cube-DeepCore. In further investigation, we analytically obtain approximately similar ranges for various neutrino mixing parameters $\mid U_{\mu 4} \mid^2$ and $\mid U_{\tau 4} \mid^2$. This work has been

carried out in collaboration with Gazal Sharma.

Investigating sterile neutrino flux in the solar neutrino data

There are compelling evidences for the existence of a fourth degree of freedom of neutrinos, i.e., sterile neutrino. In the recent studies, the role of sterile component of neutrinos has been found to be crucial, not only in particle physics, but also in astrophysics and cosmology. This has been proposed to be one of the potential candidates of dark matter. In this work, we investigate the updated solar neutrino data available from all the relevant experiments including Borexino and KamLAND solar phase in a model independent way, and obtain bounds on the sterile neutrino component present in the solar neutrino flux. The mystery of the missing neutrinos is further deepening as subsequent experiments are coming up with their results. The energy spectrum of solar neutrinos, as predicted by Standard Solar Models (SSM), is seen by neutrino experiments at different parts as they are sensitive to various neutrino energy ranges. It is interesting to note that more than 98% of the calculated standard model solar neutrino flux lies below 1 MeV. Therefore, the study of low energy neutrinos can give us better understanding and the possibility to know about the presence of antineutrino and sterile neutrino components in solar neutrino flux. As such, this work becomes interesting as we include the data from medium energy ($\sim$1 MeV) experiments, i.e., Borexino and KamLAND solar phase. In our study, we retrieve the bounds existing in literature, and rather provide more stringent limits on sterile neutrino (ν_s) flux available in solar neutrino data. This work has been carried out in collaboration with Ankush, Rishu Verma, and Gazal Sharma.

Himadri Sekhar Das

Bok Globule CB17: Polarization, extinction and distance

In this work, the results obtained from the polarimetric study of a Bok Globule CB17 in both optical and sub-millimeter wavelength are presented. The optical polarimetric observations in R-band (λ = 630 nm, $\Delta\lambda$ = 120 nm) were conducted from 1.04-meter Sampurnanand Telescope, ARIES, Nainital, India on 9th March 2016, while the sub-mm polarimetric data are taken from the SCUPOL data archive which has been reanalyzed. The contours of Herschel is an ESA space observatory with science instruments provided by European-led Principal Investigator consortia and with important participation from NASA. SPIRE 500μm dust continuum emissions of CB17 (typically a cometary-shaped globule) are overlaid on the DSS image of CB17 along with polarization vectors (optical and sub-mm). The magnetic field strength at the core of the globule is estimated to be 99μG. Using the near-infrared photometric technique and *Gaia* data, the distance to CB17 is found to be 253 ± 43 parsec. A correlation between the various quantities of the globule is also studied. It is observed that the magnetic field in the cloud core as revealed by polarization measurements at the sub-mm dust emission is found to be almost aligned along the minor axis of the globule, which fits the magnetically regulated star formation model. The misalignment between core-scale magnetic field direction and molecular outflow direction is also found. This work has been done in collaboration with G. B. Choudhury, Ajoy Barman, and Biman J. Medhi .

Photometry, spectroscopy, and polarimetry of distant comet C/2014 A4 (SONEAR)

We present an analysis of spectroscopy, photometry, and polarimetry of comet C/2014 A4 (SONEAR), which were performed during November 5-7, 2015, when its heliocentric distance was 4.2 au and phase angle was 4.7°. Long-slit spectra and photometric and linear polarimetric images were obtained using the focal reducer SCORPIO-2 attached to the prime focus of the 6m telescope BTA (SAO RAS, Russia). We simulated the behaviuor of colour and polarization in the coma presenting the cometary dust as a set of polydisperse polyshapes rough spheroids. No emission features were detected in the 3800–7200Å wavelength range. The continuum showed a reddening effect with the normalized gradient of reflectivity $21.6 \pm 0.2\%$ per 1000Å within the 4650–6200Å wavelength region. The fan-like structure in the sunward hemisphere was detected. The radial profiles of surface brightness differ for r-sdss and g-sdss filters, indicating a predominance of sub-micron and micron-sized particles in the cometary coma. The dust colour (g–r) varies from 0.75 ± 0.05^m to 0.45 ± 0.06^m along the tail. For an aperture radius near 20,000 km, the dust productions in various filters were estimated

as $Af\rho = 680 \pm 18$ cm (r-sdss) and 887 ± 16 cm (g-sdss). The polarization map shows spatial variations in polarization over the coma from about –3% near the nucleus to –8% at a cometocentric distance of about 150,000 km. Our simulations show that the dust particles are dominated (or covered) by ice and tholin-like organics. Spatial changes in the colour and polarization can be explained by particle fragmentation. This work has been done in collaboration with Oleksandra Ivanova, Igor Lukyanyk, Ludmilla Kolokolova. Marek Husarik, Vera Rosenbush, et al.

Sudipta Das

Dynamical system analysis for steep potentials

In this work, we have performed the dynamical system analysis for steep(er) exponential potentials considering different values of the steepness index n. We have performed the analysis using centre manifold theory as well as by employing numerical method. We have shown that in most of the cases, the higher values of steepness index corresponds to an unstable solution. We have shown that with this steep(er) potentials, one cannot have a phase transition from dark matter to dark energy in the past. This work has been done in collaboration with Manisha Banerjee, and Namdam Roy.

Abhirup Datta

Detailed study of the ELAIS N1 field with the uGMRT - I. Characterizing the 325 MHz foreground for redshifted 21 cm observations

In this work, we present initial results of newly upgraded Giant Metrewave Radio Telescope (uGMRT) observation of European Large-Area ISO Survey-North 1 (ELAISN1) at 325 MHz with 32 MHz bandwidth. Precise measurement of fluctuations in galactic and extragalactic foreground emission as a function of frequency as well as angular scale is necessary for detecting redshifted 21 cm signal of neutral hydrogen from cosmic dawn, epoch of reionization (EoR) and post-reionization. Here, for the first time, we have statistically quantified the galactic and extragalactic foreground sources in the ELAIS-N1 field in the form of angular power spectrum using the newly developed tapered gridded estimator (TGE). We have calibrated the data with and without direction-dependent calibration techniques, and demonstrated the effectiveness of TGE against the direction-dependent effects by using higher tapering of field of view (FoV). We have found that diffuse galactic synchrotron emission (DGSE) dominates the sky, after point source subtraction, across the angular multipole range $1115 \lesssim \ell \lesssim 5083$ and $1565 \lesssim \ell \lesssim 4754$ for direction-dependent and -independent calibrated visibilities, respectively. The statistical fluctuations in DGSE has been quantified as a power law of the form $C_\ell = A\ell^{-\beta}$. The best-fitting values of (A, β) are $(62 \pm 6mK^2, 2.55 \pm 0.3)$ and $(48 \pm 4mK^2, 2.28 \pm 0.4)$ for the two different calibration approaches. For both the cases, the power-law index is consistent with the previous measurements of DGSE in other parts of sky. This work has been done in collaboration with Arnab Chakraborty, Samir Choudhuri, Nirupam Roy, Huib Intema, Madhurima Choudhury, et al.

Extracting the 21 cm global signal using articial neural networks

The study of the cosmic dark ages, cosmic dawn, and epoch of reionization (EoR) using the all-sky averaged redshifted HI 21 cm signal, are some of the key science goals of most of the ongoing or upcoming experiments, for example, EDGES, SARAS, and the SKA. This signal can be detected by averaging over the entire sky, using a single radio telescope, in the form of a global signal as a function of only redshifted HI 21 cm frequencies. One of the major challenges faced while detecting this signal is the dominating, bright foreground. The success of such detection lies in the accuracy of the foreground removal. The presence of instrumental gain fluctuations, chromatic primary beam, radio frequency interference (RFI), and the Earths ionosphere corrupts any observation of radio signals from the Earth. Here, we propose the use of artificial neural networks (ANNs) to extract the faint redshifted 21 cm global signal buried in a sea of bright galactic foregrounds and contaminated by different instrumental models. The most striking advantage of using ANNs is the fact that, when the corrupted signal is fed into a trained network, we can simultaneously extract the signal as well as foreground parameters very accurately. Our results show that ANNs can detect the global signal with $\gtrsim$ 92 per cent accuracy even in cases of mock observations, where the instrument has some residual time-varying gain across the spectrum. This study has been done in collaboration with Madurima Choud-

hury, and Arnab Chakrabory.

Ujjal Debnath

Charge gravastars in $f(T)$ modified gravity

We have studied the four dimensional spherically symmetric stellar system in the framework of modified $f(T)$ gravity theory with electro-magnetic field. The field equations have been written for two cases, either $T' = 0$ or $f_{TT} = 0$. Next, we have discussed the charged gravastar model which has three regions: interior, shell and exterior. In the interior region, we have found the solutions of all physical quantities like density, pressure, electro-magnetic field and also the metric coefficients for both the cases. For $T' = 0$, gravastar cannot form but it forms only for the case $f_{TT} = 0$. In the exterior region, we have obtained the exterior solution for vacuum model. In the shell region, we have assumed that the interior and exterior regions join together at a place, so the intermediate region must be thin shell with the approximation $h(\equiv e^{-b}) \ll 1$. Under this approximation, we have found the analytical solutions. The proper length of the thin shell, entropy and energy content inside the thin shell have been found and they are directly proportional to the proper thickness of the shell ϵ under the approximation ($\epsilon \ll 1$). According to the Darmois-Israel formalism, we have studied the matching between the surfaces of interior and exterior regions of the gravastar. The energy density, pressure, equation of state parameter on the surface and mass of the thin shell have been obtained.

Parametrizations of dark energy models in the background of general non-canonical scalar field in D-dimensional fractal universe

We have explored non-canonical scalar field model in the background of non-flat D-dimensional fractal universe on the condition that the matter and scalar field are separately conserved. The potential V, scalar field ϕ, function f, densities, Hubble parameter and deceleration parameter can be expressed in terms of the redshift z, and these depend on the equation of state parameter w_ϕ. We have also investigated the cosmological analysis of four kinds of well known parametrization models. Graphically, we have analyzed the nature of potential, scalar field, function f, densities, the Hubble parameter and deceleration parameter. As a result, the best fitted values of the unknown parameters (w_0, w_1) of the parametrization models due to the joint data analysis (SNIa+BAO+CMB+Hubble) have been found. Furthermore, the minimum values of χ^2 function have been obtained. Also we have plotted the graphs for different confidence levels 66%, 90% and 99% contours for $(w_0,\ w_1)$ by fixing the other parameters. This work has been done in collaboration with Kazuharu Bamba.

Shantanu Desai

Robust model comparison tests of DAMA/LIBRA annual modulation

We evaluate the statistical significance of the DAMA/LIBRA claims for annual modulation using three independent model comparison techniques, viz frequentist, information theory, and Bayesian analysis. We fit the data from the DAMA/LIBRA experiment to both cosine and a constant model, and carry out model comparison by choosing the constant model as the null hypothesis. For the frequentist test, we invoke Wilk's theorem and calculate the significance using $\Delta\chi^2$ between the two models. For information theoretical tests, we calculate the difference in Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) between the two models. We also compare the two models in a Bayesian context by calculating the Bayes factor. We also search for higher harmonics in the DAMA/LIBRA data using generalized Lomb-Scargle periodogram. We finally test the sensitivity of these model comparison techniques in discriminating between pure noise and a cosine signal using synthetic data. This is the first proof of principles application of AIC, BIC as well as Bayes factor to the DAMA data. This evaluation has been done in collaboration with Aditi Krishak, and Aisha Dantulurib.

Looking for ancillary signals around GW150914

We replicated the procedure of Liu and Jackson who had found evidence for a low amplitude signal in the vicinity of GW150914. This was based upon the large correlation between the time integral of the Pearson cross-correlation coefficient in the off-source region of GW150914, and the Pearson cross-correlation in a narrow window around GW150914, for the same time lag between the two LIGO detectors as the gravitational wave signal. Our results mostly agree with those of Liu and Jackson We find the statistical significance of the observed

cross-correlation to be about 2.5σ. We also used the cross-correlation method to search for short duration signals at all other physical values of the time lag, within this 4,096 second time interval, but do not find evidence for any statistically significant events in the off-source region. This work Has been done in Collaboration with Rahul Maroju, Sristi Ram Dyuthi, and Anumandla Sukrutha.

Shanti Priya Devarapalli

Comprehensive study of a neglected contact binary TYC 5532-1333-1

A comprehensive photometric and spectroscopic analysis of the variable TYC5532-1333-1 (TYC) along with an investigation of its orbital period variation are presented for the first time. The B and V band photometric study indicates that TYC is an intermediate contact binary with degree of contact and mass ratio of 32% and ∼0.24, respectively. The derived equivalent widths from the spectroscopic study of Hα and Na-I lines reveal phase dependent variation and mutual correlation. Using the available times of minimum light, an investigation of orbital period variation shows a long-term decrease at a rate of 3.98×10^{-6} days/yr. Expected causes for such decline in the orbital period could be angular momentum loss and a quasi-sinusoidal variation due to light-time effect, probably caused by a third-body companion. The minimum mass of the third body (M_3) was derived to be 0.65 $M_{\odot}$. Our study is an attempt to evaluate and understand the evolutionary state of above-mentioned neglected contact binary. This analysis has been done in collaboration with Rukmini Jagirdar, Rajendra M. Prasad, Vinoy S. Thomas, Shehab A. Ahmed, R. Gralapally, et al.

Broja Gopal Dutta

Evidence of outflow-induced soft lags of galactic black holes

The nature of lag variation of galactic black holes remains enigmatic mostly because of non-linear and non-local physical mechanisms, which contribute to the lag of the photons coming from the region close to the central black holes. One of the widely accepted major sources of the hard lag is the inverse Comptonization mechanism. However, the exact reason, for soft lags has yet to be identified. In this work, we report a possible correlation between radio intensities of several outbursting galactic black hole candidates and amounts of soft lag. The correlation suggests that the presence of major outflows or jets changes the disk morphology along the line of sight of the observer which produces soft lags. This work has been done in collaboration with Dusmanta Patra, Arka Chatterjee, Sandip K. Chakrabarti, and Prantik Nandi.

Discovery of jet-induced soft lags of XTE J1550-564 during its 1998 outburst

X-ray time lags are complicated in nature. The exact reasons for complex lag spectra are as yet unknown. However, the hard lags, in general, are believed to be originated due to inverse Comptonization process. Recent studies on "Disk-Jet Connections" revealed that the jets are also contributing in the X-ray spectral and timing properties in a magnitude, which was more than what was predicted earlier. In this work , we first show an exact anti-correlation between X-ray time lag and radio flux for XTE J1550-546 during its 1998 outburst. We propose that the soft lags might be generated due to the change in the accretion disk structure along the line of sight during higher jet activity. This work has been done in collaboration with Arka Chaterjee, Dusmanta Patra, Sandip K. Chakrabarti, and Prantik Nandi.

Jibitesh Dutta

Linear growth index of matter perturbations in Rastall gravity

Rastall gravity theory shows notable features consistent with physical observations in comparison to the standard Einstein theory. Recently, there has been a debate about the equivalence of Rastall gravity and general relativity. Motivated by this open issue, we attempt to shed some light on this debate by analyzing the evolution of the Rastall based cosmological model at the background as well as perturbation level. Employing the dynamical system techniques, we found that at late times, the dynamics of the model resembles the ΛCDM model at the background level irrespective of the choice of Rastall's parameter. However, at the perturbation level, we found that the evolution of the growth index heavily depends on the Rastall's parameter and displays a significant deviation from

the ΛCDM model. This work has been done in collaboration with Wompherdeiki Khyllep

Thermodynamics of scalar field models with kinetic corrections

In this work, we compare the thermodynamical viability of two types of non-canonical scalar field models, with kinetic corrections: the square kinetic and square root kinetic corrections. In modern cosmology, the generalized second law of thermodynamics (GSLT) plays an important role in deciding thermodynamical compliance of a model as one cannot consider a model to be viable if it fails to respect GSLT. Hence, for comparing thermodynamical viability, we examine the validity of GSLT for these two models. For this purpose, by employing the unified first law (UFL), we calculate the total entropy of these two models in apparent and event horizons. The validity of GSLT is then examined from the autonomous systems, as the original expressions of total entropy are very complicated. Although, at the background level, both models give interesting cosmological dynamics, however, thermodynamically we found that the square kinetic correction is more realistic as compared to the square root kinetic correction. More precisely, the GSLT holds for the square kinetic correction throughout the evolutionary history except only during the radiation epoch, where the scalar field may not represent a true description of the matter content. On the other hand, the square root kinetic model fails to satisfy the GSLT in major cosmological eras. This work has been done in collaboration with Binod Chetry, and Wompherdeiki Khyllep.

Sunandan Gangopadhyay

Cosmology of Bianchi type-I metric using renormalization group approach for quantum gravity

We study the anisotropic Bianchi type-I cosmological model at late times, taking into account quantum gravitational corrections in the formalism of the exact renormalization group flow of the effective average action for gravity. The cosmological evolution equations are derived by including the scale dependence of Newton's constant G and cosmological constant Λ. We have considered the solutions of the flow equations for G at next to leading order in the infrared cutoff scale. Using these scale dependent G in Einstein equations for the Bianchi-I model, we obtain the scale factors in different directions. It is shown that the scale factors eventually evolve into FLRW universe for known matter like radiation. However, for dust and stiff matter, we find that the universe need not evolve to the FLRW cosmology in general, but can also show Kasner type behaviour. This work has been done in collaboration with Rituparna Mandal, and Amitabha Lahiri.

Holographic entanglement entropy and generalized entanglement temperature

In this work, we study the flow of holographic entanglement entropy in dimensions $d \geq 3$ in the gauge/gravity duality setup. We observe that a generalized entanglement temperature T_g can be defined, which gives the Hawking temperature T_H in the infrared region and leads to a generalized thermodynamics like law, $E = \left(\frac{d-1}{d}\right) T_g S_{REE}$, which becomes an exact relation in the entire region of the subsystem size l, including both the infrared ($l \to \infty$) as well as the ultraviolet ($l \to 0$) regions. Furthermore, in the IR limit, T_g produces the Hawking temperature T_H along with some correction terms, which bears the signature of short distance correlations along the entangling surface. Moreover, for $d \geq 3$, the IR limit of the renormalized holographic entanglement entropy gives the thermal entropy of the black hole as the leading term; however it does not have a logarithmic correction to the leading term unlike the Bañados, Teitelboim, Zanelli (BTZ) black hole ($d = 2$). The generalized entanglement temperature T_g also firmly captures the quantum mechanical to thermal crossover in the dual field theory at a critical value l_c of the subsystem size in the boundary, which we graphically represent for AdS_{3+1} and AdS_{4+1} black holes. We observe that this critical value l_c where the crossover takes place decreases with increase in the dimension of the spacetime. This work has been done in collaboration with Ashis Saha and Jyoti Prasad Saha.

Suman Ghosh

Particle creation by a massless spin-$\frac{1}{2}$ field in a warped cosmological braneworld scenario

Energy momentum tensor of a quantised massless bulk spin-$\frac{1}{2}$ field in five dimensional warped cosmological spacetimes is studied. The four dimensional part of our model represents a warped cosmological

thick brane and the scale of the extra dimension is time-dependent. We use a simple ansatz to solve the Dirac equation in the bulk that helps us to compare our results with the known four dimensional case. Renormalisation of the components of the energy momentum tensor is achieved using adiabatic regularization method. We compute the leading order finite contribution to the stress-energy tensor which is of adiabatic order six. The resulting energy and pressure densities explicitly show the effects of the so-called warping factor and the dynamic extra dimension on the created matter. We show how the energy density produced is localised to form 3-branes along the extra dimension.

Sushant G. Ghosh

Shadow cast and deflection of light by charged rotating regular black holes

We discuss the horizon properties, shadow cast, and the weak gravitational lensing of charged rotating regular black holes, in addition to mass (M) and rotation parameter (a) have an electric charge (Q) and magnetic charge (g). The considered are the generalization of the Kerr ($Q = g = 0$) and Kerr-Newman ($g = 0$) black holes. Interestingly, for a given parameter set, the apparent size of the shadow monotonically decreases and the shadow gets more distorted with increasing charge parameter Q. We put constraints on the black hole parameters with the aid of recent M87* shadow observation. The conserved quantities associated with the rotating regular black holes are calculated, and also a brief description of the weak gravitational lensing using the Gauss-Bonnet theorem is presented. Interestingly, the deflection angle decreases with the charge of the black hole. Our results *vis-à-vis* go over to the Kerr and Kerr-Newman black holes in the appropriate limits. This work has been done in collaboration with Rahul Kumar, and Anzhong Wang.

Black hole parameter estimation from its shadow

The Event Horizon Telescope (EHT), a global submillimeter wavelength very long baseline interferometry array, unveiled event-horizon-scale images of the supermassive black hole M87* as an asymmetric bright emission ring with a diameter of 42 ± 3 μas, and it is consistent with the shadow of a Kerr black hole of general relativity. A Kerr black hole is also a solution of some alternative theories of gravity, while several modified theories of gravity admit non-Kerr black holes. While earlier estimates for the M87* black hole mass, depending on the method used, fall in the range $\approx 3\times10^9 M_\odot - 7\times10^9 M_\odot$, the EHT data indicated a mass for the M87* black hole of $(6.5\pm0.7)\times10^9 M_\odot$. This offers another promising tool to estimate black hole parameters and to probe theories of gravity in its most extreme region near the event horizon. The important question arises: Is it possible by a simple technique to estimate black hole parameters from its shadow, for arbitrary models? In this work, we present observables, expressed in terms of ordinary integrals, characterizing a haphazard shadow shape to estimate the parameters associated with black holes, and then illustrate its relevance to four different models: Kerr, Kerr−Newman, and two rotating regular models. Our method is robust, accurate, and consistent with the results obtained from existing formalism, and it is applicable to more general shadow shapes that may not be circular due to noisy data. This work has been done in collaboration with Rahul Kumar

Rupjyoti Gogoi

Formation of disc galaxies around $Z \sim 2$

We present combined evolution of morphological and stellar properties of galaxies on the two sides of z = 2 (2.0 < z < 4.0 and 1.5 < z < 2.0) in CDFS, with ground-based spectroscopic redshifts. We perform bulge-disc decomposition on their images in J and H filters, from the 3DHST Legacy Survey obtained using HST/WFC3. Combining morphological information with stellar properties, we provide a detailed account of the formation/growth of discs and spheroids around $z \sim 2$. The fraction of two-component (bulge+disc) systems increases from 46 per cent for z > 2 to 70 per cent for z < 2, compensating for the fall in population of pure discs and pure spheroids. All quiescent outliers of our full sample on the main sequence are two-component systems, belonging to the lower redshift range (z < 2). The doubling of stellar mass of two-component systems and decrease in their SFR by the same factor, suggests that mechanisms involved in morphological transformations are also responsible for the quenching of their star formation activity. Interestingly, while there is substantial increase in the size

(2.5 times) and mass (5 times) of pure discs, from z > 2 to z < 2, pure spheroids maintain roughly the same values. Additionally, while bulge hosting discs witness an expansion in scale length (1.3 times), their bulge sizes as well as bulge to total light ratio see no evolution, suggesting that $z \sim 2$ is pre-dominantly a disc formation period. This work has been done in collaboration with Sonali Sachdeva,Kanak Saha, Ajit Kembhavi,and Somak Raychaudhury.

Unravelling the unusually curved X-ray spectrum of RGB J0710+591 using AstroSat *observations*

We report the analysis of simultaneous multi-wavelength data of the high energy peaked blazar RGB J0710+591 from the LAXPC, SXT and UVIT instruments on-board *AstroSat*. The wide band X-ray spectrum (0.35 - 30 keV) is modelled as synchrotron emission from a non-thermal distribution of high energy electrons. The spectrum is unusually curved, with a curvature parameter $\beta_p \sim 6.4$ for a log parabola particle distribution, or a high energy spectral index $p_2 > 4.5$ for a broken power-law distribution. The spectrum shows more curvature than an earlier quasi-simultaneous analysis of *Swift*-XRT/*Nu*STAR data where the parameters were $\beta_p \sim 2.2$ or $p_2 \sim 4$. It has long been known that a power-law electron distribution can be produced from a region where particles are accelerated under Fermi process and the radiative losses in acceleration site decide the maximum attainable Lorentz factor, γ_{max}. Consequently, this quantity decides the energy at which the spectrum curves steeply. We show that such a distribution provides a more natural explanation for the *AstroSat* data as well as the earlier XRT/*Nu*STAR observation, making this as the first well constrained determination of the photon energy corresponding to γ_{max}. This in turn provides an estimate of the acceleration time-scale as a function of magnetic field and Doppler factor. The UVIT observations are consistent with earlier optical/UV measurements and reconfirm that they plausibly correspond to a different radiative component than the one responsible for the X-ray emission. This analysis has been done in collaboratio with Pranjupriya Goswami, Atreyee Sinha, Sunil Chandra, Ranjeev Misra, Varsha Chitnis, et al.

Gaurav Goswami

Enhancement of axion decay constants in type IIA theory?

We investigate the possibility of enhancement of effective axion decay constant in well controlled constructions in string theory. To this end, we study the dynamics of axions arising in the compactifications of type IIA string theory on Calabi-Yau orientifolds with background fluxes (with non-perturbative effects included to ensure stabilization of all moduli). In this setup, we attempt to obtain large effective axion decay constant in two different ways: by searching for a direction in field space, in which the potential is sufficiently flat and by arriving at a very explicit stringy embedding of the Kim-Nilles-Peloso (KNP) alignment mechanism. We do not find super-Planckian effective decay constants by either of the approaches. Furthermore, we find that the alignment angle of KNP mechanism can not be made arbitrarily small by adjusting the fluxes.

Trans-Planckian censorship conjecture and non-thermal post-inflationary history

The recently proposed Trans-Planckian Censorship conjecture (TCC) can be used to constrain the energy scale of inflation. The conclusions, however, depend on the assumptions about post-inflationary history of the Universe. For example, in the standard case of a thermal post-inflationary history in which the Universe stays radiation dominated at all times from the end of inflation to the epoch of radiation matter equality, TCC has been used to argue that the Hubble parameter during inflation, $H_{\rm inf}$, is below $\mathcal{O}(0.1)$ GeV. Cosmological scenarios with a non-thermal post-inflationary history are well-motivated alternatives to the standard picture, and it is interesting to find out the possible constraints which TCC imposes on such scenarios. In this work, we find out the amount of enhancement of the TCC compatible bound on $H_{\rm inf}$ if post-inflationary history before nucleosynthesis is non-thermal. We then argue that if TCC is correct, for a large class of scenarios, it is not possible for the universe to have undergone a phase of moduli domination. This work has been done in collaboration with Mansi Dhuria.

Umananda Dev Goswami

Supersymmetric hybrid inflation with non-minimal coupling to gravity

The paradigm of cosmic inflation has been studied using the simplest model based on the idea of supersymmetric hybrid inflation with non-minimal coupling to gravity, specially under the slow-roll approximation following the superconformal approach to supergravity. It is found that within a range of values of the non-minimal coupling parameter ξ, the model can accommodate the inflation data reported by the Planck (n_s and upper limit of r) and BICEP2/Keck (upper limit of r) collaborations. The study shows that the most probable value of ξ should be $\sim 0.0134 \pm 0.0005$. That is coupling is found to be very weak. Within this range of ξ, the values of r estimated from our model for $50 - 70$ e-foldings are found to lay well below the upper limits set by the Planck and BICEP2/Keck collaborations. Similarly, values of n_s obtained for the said parameters are in good agreement with its latest data of the Planck collaboration. The constraint equations for running of the scalar spectral index n_{sk} and its running n_{skk} are derived from the numerical solutions of our model for these parameters. These equations can be used to test our model from the data of future cosmological observations.

Shivappa Bharamappa Gudennavar

Are narrow-line Seyfert 1 galaxies powered by low-mass black holes?

Narrow-line Seyfert 1 galaxies (NLS1s) are believed to be powered by the accretion of matter onto low-mass black holes (BHs) in spiral host galaxies with BH masses $M_{BH} \sim 10^6$ to 10^8 $M_\odot$. However, the broadband spectral energy distribution of the γ-ray-emitting NLS1s are found to be similar to flat-spectrum radio quasars. This challenges our current notion of NLS1s having low M_{BH}. To resolve this tension of low M_{BH} values in NLS1s, we fitted the observed optical spectrum of a sample of radio-loud NLS1s (RL-NLS1s), radio-quiet NLS1s (RQ-NLS1s), and radio-quiet broad-line Seyfert 1 galaxies (RQ-BLS1s) of ~ 500 each with the standard Shakura-Sunyaev accretion disk (AD) model. For RL-NLS1s, we found a mean $\log(M_{\rm BH}^{\rm AD}/M_\odot)$ of 7.98 ± 0.54. For RQ-NLS1s and RQ-BLS1s, we found mean $\log(M_{\rm BH}^{\rm AD}/M_\odot)$ of 8.00 ± 0.43 and 7.90 ± 0.57, respectively. While the derived $M_{\rm BH}^{\rm AD}$ values of RQ-BLS1s are similar to their virial masses, for NLS1s the derived $M_{\rm BH}^{\rm AD}$ values are about an order of magnitude larger than their virial estimates. Our analysis, thus indicates that NLS1s have M_{BH} similar to RQ-BLS1s, and their available virial M_{BH} values are underestimated, influenced by their observed relatively small emission line widths. Considering Eddington ratio as an estimation of the accretion rate and using $M_{\rm BH}^{\rm AD}$, we found the mean accretion rate of our RQ-NLS1s, RL-NLS1s, and RQ-BLS1s as $0.06^{+0.16}_{-0.05}$, $0.05^{+0.18}_{-0.04}$ and $0.05^{+0.15}_{-0.04}$, respectively. Our results therefore, suggest that NLS1s have BH masses and accretion rates that are similar to BLS1s. This work has been done in collaboration with Gayathri Viswanath, C. S. Stalin, Suvendu Rakshit, Kshama S. Kurian, K. Ujjwal, et al.

Unveiling the temporal properties of MAXI J1820+070 through AstroSat observations

We present here the results of the first broadband simultaneous spectral and temporal studies of the newly detected black hole binary MAXI J1820+070 as seen by Soft X-ray Telescope and Large Area X-ray Proportional Counter (LAXPC) on board AstroSat. The observed combined spectra in the energy range 0.7-80 keV were well modelled using disk blackbody emission, thermal Comptonization, and a reflection component. The spectral analysis revealed that the source was in its hard spectral state ($\Gamma = 1.61$) with a cool disk ($kT_{in} = 0.22keV$). We report the energy dependent time-lag and root mean squared (rms) variability at different frequencies in the energy range 3-80 keV using LAXPC data. We also modelled the flux variability using a single-zone stochastic propagation model to quantify the observed energy dependence of time lag and fractional rms variability, and then compared the results with that of Cygnus X-1. Additionally, we confirm the detection of a quasi-periodic oscillation with the centroid frequency at 47.7 mHz. This study has been done in collaboration with Sneha Prakash Mudambe, Bari Maqbool Bhat, Ranjeev Misra, Sabhya Hebbar, J. S. Yadav, et al.

Sarbari Guha

Thermodynamics of FRW universe with Chaplygin gas models

In this work, we have examined the validity of the generalized second law of thermodynamics (GSLT)

in an expanding Friedmann Robertson Walker (FRW) universe filled with different variants of Chaplygin gases. Assuming that the universe is a closed system bounded by the cosmological horizon, we first present the general prescription for the rate of change of total entropy on the boundary. In the subsequent part, we have analyzed the validity of the generalised second law of thermodynamics on the cosmological apparent horizon and the cosmological event horizon for different Chaplygin gas models of the universe. The analysis is supported with the help of suitable graphs to clarify the status of the GSLT on the cosmological horizons. In the case of the cosmological apparent horizon, we have found that some of these models always obey the GSLT, whereas the validity of GSLT on the cosmological event horizon of all these models depend on the choice of free parameters in the respective models. This work has been done in collaboration with Samarjit Chakraborty.

On the gravitational entropy of accelerating black holes

We have examined the validity of a proposed definition of gravitational entropy in the context of accelerating black hole solutions of the Einstein field equations, which represent the realistic black hole solutions. We have adopted a phenomenological approach proposed in Rudjord et al. and expanded by Romero et al. in which the Weyl curvature hypothesis is tested against the expressions for the gravitational entropy. Considering the C-metric for the accelerating black holes, we have evaluated the gravitational entropy, and the corresponding entropy density for four different types of black holes, namely, non-rotating black hole, non-rotating charged black hole, rotating black hole and rotating charged black hole. We end up by discussing the merits of such an analysis and the possible reason of failure in the particular case of rotating charged black hole and comment on the possible resolution of the problem.

Mamta Gulati

Ram pressure stripping: An analytical approach

We take an analytical approach to study ram pressure stripping, using simple models for discs and the distribution of halo gas to look at this phenomenon in cluster, group and galaxy haloes. We also study variations in galaxy properties and redshift. In each case, we model the worst-case scenario (i.e., the maximum effect resulting from ram pressure). We show that the worst-case scenario is not affected greatly by changes in redshift. We find that gas discs in galaxies with a higher spin parameter are stripped sooner than galaxies with a smaller spin parameter. Galaxies in cluster haloes are stripped of gas more efficiently compared with group and galaxy haloes, because they have a higher infall speed and a higher density of gas in the intra-cluster medium (i.e., as a result of a greater retention of baryons). We comment on the limitations of our model, and we look at and illustrate a situation where a significant amount of gas may be retained in the galaxy disc. Finally, we discuss the implications for star formation in galaxies during infall into haloes. This work has been done in collaboration with Ankit Singh, and Jasjeet S. Bagla.

Priya Hasan

GAIA: The 3D milky way mapper

GAIA (Global Astrometric Interferometer for Astrophysics) is a mission of the European Space Agency (ESA), which will make the largest, most precise three dimensional map of our galaxy by an unparalleled survey of one per cent of the galaxy's population of 100 billion stars with the precision of micro arcseconds. This article briefly reviews GAIA, the data releases (DR), and the possible implications of this mission. We introduce the DR1 and DR2 data releases and the scientific outcomes of DR1 as a forerunner to the DR2 of this one-of-a-kind mission. The DR2 was released on 25 th April 2018 and this study aims to prepare the reader for this great milestone in astronomy.

K. P. Harikrishnan

Quantifying information loss on chaotic attractors through recurrence networks

We propose an entropy measure for the analysis of chaotic attractors through recurrence networks, which are un-weighted and un-directed complex networks constructed from time series of dynamical systems using specific criteria. We show that the proposed measure converges to a constant value with increase in the number of data points on the attractor (or the number of nodes on the network)

and the embedding dimension used for the construction of the network, and clearly distinguishes between the recurrence network from chaotic time series and white noise. Since the measure is characteristic to the network topology, it can be used to quantify the information loss associated with the structural change of a chaotic attractor in terms of the difference in the link density of the corresponding recurrence networks. We also indicate some practical applications of the proposed measure in the recurrence analysis of chaotic attractors as well as the relevance of the proposed measure in the context of the general theory of complex networks. This work has been done in collaboration with Ranjeev Misra, and G. Ambika

Jessy Jose

A novel survey for young substellar objects with the W-band filter: The coolest and lowest mass members of the Serpens-South Star-forming region

Given its relative proximity ($\sim$ 430 pc), compact size ($< 20'$), young age ($\sim$ 0.5 Myr), and rich number of young stellar objects, the Serpens-South star-forming region is a promising site for studying young substellar objects, yet the low-mass members of this region remain largely undiscovered. In our deep photometric survey using a custom 1.45 μm filter (W-band), as well as standard J and H near-IR filters using 3.6m Canada-France-Hawaii Telescope (CFHT), we identify candidate low-mass young brown dwarfs in the Serpens-South region. We constructed a reddening-insensitive index (Q) by combining J, H and W-band photometry for survey objects, in order to identify candidate low-mass members of Serpens based on the strength of the water-absorption feature at 1.45 μm in the atmospheres of mid-M and later objects. We then conducted spectroscopic follow-up using ArCoIRIS spectrograph of 4m Blanco Telescope to confirm youth and spectral type for our candidates. This is the first survey to identify the very low-mass and coolest members of Serpens-South. We identify four low-mass candidate Serpens members, which all display IR excess emission, indicating the likely presence of circumstellar disks around them. One of the four candidate low-mass members in our list, SERP182918-020245, exhibits Paβ and Brγ emission features, confirming its youth and ongoing magnetospheric accretion. Our new candidate members have spectral types >M4 and are the coolest and lowest mass candidate members yet identified in Serpens-South. This survey has been done in collaboration with Beth A. Biller, Loic Albert, Sophie Dubber, Katelyn Allers, Gregory J Herezeg, et al.

Md. Mehedi Kalam

Analytical model of strange star in Durgapal space-time.

we have presented a new strange star model based on Durgapal IV metric. Here, we have applied a specific method to study the inner physical properties of the compact objects 4U 1702-429, 2A 1822-371, PSR J1756-2251, PSR J1802-2124 and PSR J1713+0747, and calculated central density (ρ_0), surface density (ρ_b), central pressure (p_0), surface red-shift (Z_s), compactness and probable radius of the above mentioned star. Further, we perform different tests to study the stability of our model and finally we are able to give an equation based on pressure and density, i.e., probable equation of state (EoS) which has an important significances in the field of astrophysics. This work has been done in collaboration with Rabiul Islam, and Sajahan Molla.

Nishikanta Khandai

The population of galaxies that contribute to the HI mass function

We look at the contribution of different galaxy populations to the atomic hydrogen (HI) mass function (HIMF) and the HI density parameter, $\Omega_{\rm HI}$, in the local universe. Our analysis is based on a sample of 7857 HI-selected galaxies from a volume common to the SDSS and ALFALFA (40% catalogue – α.40) surveys. We define different populations of galaxies in the colour(u-r)-magnitude ($M_{\rm r}$) plane and compute the HIMF for each of them. Additionally, we compute the HIMF for dark galaxies; these are undetected in SDSS and represent $\sim$ 2% of the total sample. We find that the luminous red population dominates the total HIMF for $\log_{10}(M_{\rm HI}h_{70}^2/{\rm M}_\odot) \geq 10.4$. The full red population – luminous and faint – represents about $\sim$ 17% of the $\Omega_{\rm HI}$ budget, while that of the dark population is $\sim$ 3%. The HIMF about the knee, $\log_{10}(M_{\rm HI}h_{70}^2/{\rm M}_\odot) \in [8, 10.4]$, is dominated by the faint and luminous blue populations, the latter dominating at larger masses in this interval.

Their total contribution to $\Omega_{\rm HI}$ is $\sim 55-70\%$, the variation depending on the definition of population. The dominant populations at the low mass end, $\log_{10}(M_{\rm HI}h_{70}^2/{\rm M}_\odot) \leq 8.0$ are the faint blue and faint bluer populations, the latter's dominance being sensitive to its definition. The full blue (blue–bluer luminous and faint) population represents $\sim 80\%$ of $\Omega_{\rm HI}$. A bimodal HIMF suggested by our results is, however, not seen since the amplitude of the HIMF of the luminous red population is small compared to that of the luminous blue population. This work has been done in collaboration with Saili Dutta, and Biprateep Dey.

Nagendra Kumar

Turbulence effect on the stability of molecular cloud

Observations show that molecular clouds are the sites of star formation and have a clumpy structure. Since some properties of massive molecular clouds can not be explained by isothermal equation of state, so an alternative form of equation of state, i.e. logatropic equation of state is considered to study the stability of molecular cloud. So stability of self-gravitating, magnetized and warm molecular cloud is studied taking into account the turbulence effect. We consider molecular cloud as a partially ionized composed of ions and neutrals, self-gravitating, warm and magnetized medium. A logarithmic term is added in the equation of state to include the effect of turbulent motion. A biquadratic dispersion relation is obtained, and is discussed in a special case by ignoring friction between ions and neutrals. It is found that waves propagate with faster speed if perturbation wavelength is less than the Jeans length of the ion component and greater than the Jeans length of the neutral component. This work has been done in collaboration with Meenakshi Yadav.

Suresh Kumar

Testing the warmness of dark matter

Dark matter (DM) as a pressureless perfect fluid provides a good fit of the standard ΛCDM model to the astrophysical and cosmological data. In this work, we investigate two extended properties of DM: a possible time dependence of the equation of state of DM via Chevallier-Polarski-Linder parametrization, $w_{\rm dm} = w_{\rm dm0} + w_{\rm dm1}(1-a)$, and the constant non-null sound speed $\hat{c}^2_{\rm s,dm}$. We analyze these DM properties on top of the base ΛCDM model by using the data from Planck cosmic microwave background (CMB) temperature and polarization anisotropy, baryonic acoustic oscillations (BAO) and the local value of the Hubble constant from the Hubble Space Telescope (HST). We find new and robust constraints on the extended free parameters of DM. The most tight constraints are imposed by CMB + BAO data, where the three parameters $w_{\rm dm0}$, $w_{\rm dm1}$ and $\hat{c}^2_{\rm s,dm}$ are respectively constrained to be less than 1.43×10^{-3}, 1.44×10^{-3} and 1.79×10^{-6} at 95% CL. All the extended parameters of DM show consistency with zero at 95% CL, indicating no evidence beyond the CDM paradigm. We notice that the extended properties of DM significantly affect several parameters of the base ΛCDM model. In particular, in all the analyses performed here, we find significantly larger mean values of H_0 and lower mean values of σ_8 in comparison to the base ΛCDM model. Thus, the well-known H_0 and σ_8 tensions might be reconciled in the presence of extended DM parameters within the ΛCDM framework. Also, we estimate the warmness of DM particles as well as its mass scale, and find a lower bound: ~ 500 eV from our analyses. This work has been done in collaboration with Rafael C. Nunes, and Santosh Kumar Yadav.

Constraints on Bianchi type-I spacetime extension of the standard ΛCDM model

We consider the simplest anisotropic generalization, as a correction, to the standard ΛCDM model, by replacing the spatially flat Robertson-Walker metric by the Bianchi type-I metric, which brings in a new term $\Omega_{\sigma0}a^{-6}$ (mimicking the stiff fluid) in the average expansion rate $H(a)$ of the universe. From Hubble and Pantheon data, relevant to the late universe ($z \lesssim 2.4$), we obtain the constraint $\Omega_{\sigma0} \lesssim 10^{-3}$, in line with the model independent constraints. When the baryonic acoustic oscillations and cosmic microwave background (CMB) data are included, the constraint improves by 12 orders of magnitude, i.e., $\Omega_{\sigma0} \lesssim 10^{-15}$. We find that this constraint could alter neither the matter-radiation equality redshift nor the peak of the matter perturbations. Demanding that the expansion anisotropy has no significant effect on the standard Big Bang Nucleosynthesis (BBN), we find the constraint $\Omega_{\sigma0} \lesssim 10^{-23}$. We show explicitly that the constraint from BBN renders the expansion

anisotropy irrelevant to make a significant change in the CMB quadrupole temperature, whereas the constraint from the cosmological data in our model provides the temperature change up to $\sim 11\,\mathrm{mK}$, though it is much beyond the CMB quadrupole temperature. This work has been done in collaboration with Ozgur Akarsu, Shivani Sharma, and Luigi Tedesco.

Smriti Mahajan

Galaxy And Mass Assembly (GAMA): Properties and evolution of red spiral galaxies

We use multiwavelength data from the Galaxy And Mass Assembly (GAMA) survey to explore the cause of red optical colours in nearby ($0.002 < z < 0.06$) spiral galaxies. We show that the colours of red spiral galaxies are a direct consequence of some environment-related mechanism(s) that has removed dust and gas, leading to a lower star formation rate. We conclude that this process acts on long time-scales (several Gyr) due to a lack of morphological transformation associated with the transition in optical colour. The specific star formation rate (sSFR) and dust-to-stellar mass ratio of red spiral galaxies is found to be statistically lower than blue spiral galaxies. On the other hand, red spirals are on average 0.9 dex more massive, and reside in environments 2.6 times denser than their blue counterparts. We find no evidence of excessive nuclear activity, or higher inclination angles to support these as the major causes for the red optical colours seen in ≥ 47 per cent of all spirals in our sample. Furthermore, for a small subsample of our spiral galaxies that are detected in H I, we find that the SFR of gas-rich red spiral galaxies is lower by 1 dex than their blue counterparts. This work has been done in collabration with Kirti Kamal Gupta, Rahul Rane, Michael J. I. Brown, Steven Phillipps, Joss Bland-Hawathorn, et. al.

Titus K. Mathew

First law of thermodynamics and emergence of cosmic space in a non-flat universe

The emergence of cosmic space as cosmic time progresses is an exciting idea advanced by Padmanabhan to explain the accelerated expansion of the universe. The generalization of Padmanabhan's conjecture to the non-flat universe has resulted in scepticism about the choice of volume such that the law of emergence can not be appropriately formulated if one uses proper invariant volume. The deep connection between the first law of thermodynamics and the law of emergence, motivate us to explore the status of the first law in a non-flat universe when one uses proper invariant volume. We have shown that the first law of thermodynamics, $dE = TdS + WdV$ cannot be formulated properly for a non-flat universe using proper invariant volume. We have also investigated the status of the first law of the form $-dE = TdS$ in a non-flat universe. We have shown that the energy change dE_V within the horizon and the outward energy flux are not equivalent to each other in a non-flat universe when we use the proper invariant volume. We further point out that the consistency between the above two forms of the first law claimed in will hold only with the use of the real volume of the horizon. The failure in formulating the first law of thermodynamics with the use of invariant volume shows that the invariant volume will be a poor choice to describe any thermodynamic process in cosmology. This work has been done in collaboration with Hareesh Thuruthipilly, and P.B. Krishna.

Dynamical system analysis and thermal evolution of the causal dissipative model

The dynamical system behaviour and thermal evolution of a homogeneous and isotropic dissipative universe are analyzed. The dissipation is driven by the bulk viscosity and the evolution of bulk viscous pressure is described using the full causal Israel-Stewart theory. We find that for $s = 1/2$, the model possesses a prior decelerated epoch,which is unstable and a stable future accelerated epoch. From the thermodynamic analysis, we have verified that the local as well as the generalised second law of thermodynamics are satisfied throughout the evolution of the universe. We also show that the convexity condition is satisfied at the end stage of the universe, which implies an upper bound to the evolution of the entropy. For, the case $s < 1/2$ is ruled out since it does not predict the conventional evolutionary stages of the universe. On the other hand, the case $s > 1/2$ does imply a prior decelerated and a late de Sitter epochs, but both of them are unstable fixed points. The thermal evolution corresponding to the same case implies that GSL is satisfied at both the epochs but convexity condition is violated by both, so that entropy growth is unbounded. Hence for $s > 1/2$, the model does not

give a stable evolution of the universe. This work has been done in collaboration with N.D. Jerin Mohan, P.B. Krishna, and Athira Sasidharan.

Irom Ablu Meitei

Generalized Klein-Gordon equation and quantum gravity corrections to tunnelling of scalar particles from Kerr-Newman black hole

In this work, we deduce the generalized Klein-Gordon equation in curved spacetime in the presence of an electromagnetic field from first principles, using the generalized uncertainty principle. Using this equation, we study the tunnelling of scalar particles from a Kerr-Newman black hole. Corrections to the Hawking temperature and entropy of the black hole due to quantum gravity effects are discussed. This work has been done in collaboration with A. Keshwarjit Singh, Talem Ibungochouba Singh, and K. Yugindro Singh.

Effect of GUP on Hawking radiation of BTZ black hole

The Hawking radiation of BTZ black hole is investigated based on generalized uncertainty principle effect by using Hamilton-Jacobi method and Dirac equation. The tunnelling probability and the Hawking temperature of the spin 1/2 particles of the BTZ black hole is investigated using modified Dirac equation based on the GUP. The modified Hawking temperature for Fermion crossing the black hole horizon includes the mass parameters of the black hole, angular momentum, energy and also outgoing mass of the emitted particle. Besides, considering the effect of GUP into account, the modified Hawking radiation of massless particle from a BTZ black hole is investigated using Damour and Ruffini method, tortoise coordinate transformation and modified Klein-Gordon equation. The relation between the modified Hawking temperature obtained by using Damour-Ruffini method and the energy of the emitted particle is derived. The original Hawking temperature is also recovered in the absence of quantum gravity effects. This work has been done in collaboration with Talem Ibungochouba Singh, and Y. Kenedy Meitei

Hameeda Mir and Rizwan Ul Haq Ansari

Modified theory of gravity and clustering of multi component system of galaxies

We analyze the clustering of galaxies using a modified theory of gravity, in which the field content of general relativity has been increased. This increas changes the large distance behaviour of the theory, and in weak field approximation, it will also modify the large distance behaviour of Newtonian potential. So, we analyze the clustering of multi-component system of galaxies interacting through this modified Newtonian potential. We obtain the partition function for this multi-component system, and study the thermodynamics of this system, and we analyze the effects of the large distance modification to the Newtonian potential on Helmholtz free energy, internal energy, entropy, pressure and chemical potential of this system, and we obtain also the modified distribution function and the modified clustering parameter for this system, and hence, observe the effect of large distance modification of Newtonian potential on clustering of galaxies. This study has been done in collaboration with Behnam Pourhassasn, Mir Faizal, C.P. Masroor, and P. K. Suresh.

Sourav Mitra

Heavy dark matter particle annihilation in dwarf spheroidal galaxies: Radio signals at the SKA telescope

A weakly interacting dark matter candidate is difficult to detect at high-energy colliders like the LHC, if its mass is close to, or higher than a TeV. On the other hand, pair-annihilation of such particles may give rise to e^+e^- pairs in dwarf spheroidal galaxies (dSph), which in turn can lead to radio synchrotron signals that are detectable at the upcoming Square Kilometre Array (SKA) telescope within a moderate observation time. We investigate the circumstances under which this complementarity between collider and radio signals of dark matter can be useful in probing physics beyond the standard model of elementary particles. Both particle physics issues and the roles of diffusion and electromagnetic energy loss of the e are taken into account. First, the criteria for detectability of trans-TeV dark matter are analysed independently of the particle physics model(s) involved. We, thereafter, use some bench-

marks based on a popular scenario, namely, the minimal supersymmetric standard model. It is, thus, shown that the radio flux from a dSph like Draco should be observable in about 100 hours at the SKA, for dark matter masses upto 4-8 TeV. In addition, the regions in the space spanned by astrophysical parameters, for which such signals should be detectable at the SKA, are marked out. This work has been done in collaboration with Arpan Kar, Biswarup Mukhopadhyaya, and Tirthankar Roy Choudhury.

Constraints on dark matter annihilation in dwarf spheroidal galaxies from low frequency radio observations

We present the first observational limits on the predicted synchrotron signals from particle dark matter annihilation models in dwarf spheroidal galaxies at radio frequencies below 1 GHz. We use a combination of survey data from the Murchison Widefield Array (MWA) and the Giant Metrewave Radio Telescope to search for diffuse radio emission from 14 dwarf spheroidal galaxies. For in situ magnetic fields of 1 μG and any plausible value for the diffusion coefficient, our limits do not constrain any dark matter models. However, for stronger magnetic fields, our data might provide constraints comparable to existing limits from gamma-ray and cosmic-ray observations. Predictions for the sensitivity of the upgraded MWA show that models with dark matter particle mass up to ~ 1.6 TeV (1 TeV) may be constrained for a magnetic field of 2 μG (1 μG). While much deeper limits from the future low frequency Square Kilometre Array (SKA) will challenge the LHC in searches for dark matter particles, the MWA provides a valuable first step toward the SKA at low frequencies. This work has been done in collaboration with Arpan Kar, Biswarup Mukhopadhyaya, Tirthankar Roy Choudhury, and Steven Tingay.

Aditya Sow Mondal and Biplab Raychaudhuri

Study of the reflection spectrum of the bright atoll source GX 3+1 with NuSTAR

We report on the NuSTAR observation of the atoll type neutron star (NS) low-mass X-ray binary GX 3+1 performed on October 17, 2017. The source was found in a soft X-ray spectral state with $3-70$ KeV luminosity of $L_{\rm X} \sim 3\times10^{37}$ ergs s^{-1} ($\sim 16\%$ of the Eddington luminosity), assuming a distance of 6 kpc. A positive correlation between intensity and hardness ratio suggests that the source was in the banana branch during this observation. The broadband $3-70$ KeV nustar spectral data can be described by a two-component continuum model consisting of a disk blackbody ($kT_{\rm disc} \sim 1.8$ KeV) and a single temperature blackbody model ($kT_{\rm bb} \sim 2.7$ KeV). The spectrum shows a clear and robust indication of relativistic reflection from the inner disc, which is modelled with a self-consistent relativistic reflection model. The accretion disc is viewed at an inclination of $i \simeq 22-26$ degree and extended close to the NS, down to $R_{\rm in} = (1.2-1.8)R_{\rm ISCO}$ ($\simeq 6.1-9.1\,R_g$ or $14-20.5$ km), which allows an upper limit on the NS radius (≤ 13.5 km). Based on the measured flux and the mass accretion rate, the maximum radial extension for the boundary layer is estimated to be $\sim 6.3\,R_g$ from the NS surface. However, if the disc is not truncated by the boundary layer but by the magnetosphere, an estimated upper limit on the polar magnetic field would be of $B \leq 6\times10^8$ G. This observation has been done in collaboration with Gulab C. Dewangan

Pradip Mukherjee

A new action for non-relativistic particle in curved background

We obtain a new form for the action of a non-relativistic particle coupled to Newtonian gravity. The result is different from that existing in the literature which, as shown here, is riddled with problems and inconsistencies. The present derivation is based on the formalism of Galilean gauge theory, introduced by us as an alternative method of analysing non-relativistic symmetries in gravitational background. This work has been done in collaboration with Rabin Banerjee.

Constrained Hamiltonian analysis of a non-relativistic Schrodinger field coupled with Chern-Simons gravity

The coupling is achieved by the recently advanced Galilean gauge theory. The calculations are repeated with a truncated model to show that deviation from Galilean gauge theory makes the theory untenable. The issue of non-relativistic spatial diffeomorphism is discussed in this context. This

work has been done in collaboration with Abdus Sattar.

Hemwati Nandan

Analytic solutions of the geodesic equation for Reissner-Nordstrm-(anti-)de Sitter black holes surrounded by different kinds of regular and exotic matter fields

The purpose of this study is the derivation of the equation of motion for particles in the spacetime of Reissner-Nordstrm-(anti-)de Sitter black holes in the background of different kinds of regular and exotic matter fields. The complete analytical solutions of the geodesic equations are given in terms of the elliptic Weierstra β-$\wp$ function and the hyperelliptic Kleinian σ-function. Finally, after analyzing the geodesic motion of test particles and light using parametric diagrams and effective potentials, we present a list of all possible orbits. This work has been done in collaboration with Arindam Kumar Chatterjee, Kai Flathmann, and Anik Rudra.

Long-term (2005-2012) measurements of near-surface air pollutants at an urban location in the Indo-Gangetic Basin

Simultaneous long-term measurements of near-surface air pollutants at an urban station, New Delhi, were studied during $2005 - 2012$ to understand their distribution on different temporal scales. The annual mean mass concentrations of Nitrogen dioxide (NO_2), Sulphur dioxide (SO_2), particulate matter less than $10\mu m(PM_{10})$ and suspended particulate matter (SPM) were found to be $62.0 \pm 27.6, 12.5 \pm 8.2, 253.7 \pm 134$ and $529.2 \pm 213.1 \mu g/m^3$, respectively. The $24 - hr$ mean mass concentrations of NO_2, PM_{10} and SPM were exceeded on $\sim 27\%, 87\%$ and 99% days that of total available measurement days to their respective National Ambient Air Quality Standard (NAAQS) level. However, it never exceeded for SO_2, which could be attributed to reduction of Sulphur in diesel, use of cleaner fuels such as compressed natural gas, LPG, etc. The mean mass concentrations of measured air pollutants were found to be the highest during the winter/post-monsoon seasons, which are of concern for both climate and human health. The annual mean mass concentrations of NO_2, PM_{10} and SPM showed an increasing trend, while SO_2 appears to be decreasing since 2008. Air mass cluster analysis showed that north-northwest trajectories accounted for the highest mass concentrations of air pollutants (more prominent in the winter/post-monsoon season); however, the lowest were associated with the southeast trajectory cluster. This work has been done in collaboration with Nanda Kishore, Atul K. Srivastava, Chhavi P. Pandey, S Agrawal, Narendra Singh et al.

Biswajit Pandey

Can we constrain the dark energy equation of state parameters using conguration entropy ?

We propose a new scheme for constraining the dark energy equation of state parameter/parameters based on the study of evolution of conguration entropy. We analyze a set of one parameter and two parameters dynamical dark energy models and find that the derivative of the configuration entropy in all the dynamical dark energy models, exhibit a minimum. The magnitude of the minimum of the entropy rate is decided by both the parametrization of the equation of state as well as the associated parameters. The location of the minimum of the entropy rate is less sensitive to the form of the parametrization but depends on the associated parameters. We determine the best fit equations for the location and magnitude of the minimum of the entropy rate in terms of the parameter/parameters of the dark energy equation of state. These relations would allow us to constrain the dark energy equation of state parameter/parameters for any given parametrization provided the evolution of the configuration entropy in the Universe is known from observations. This work has been done in collaboration with Biswajit Das.

Unravelling the cosmic web: An analysis of the SDSS DR14 with the local dimension

We analyse a volume-limited galaxy sample from the Sloan Digital Sky Survey (SDSS) in order to study the environments of galaxies on different length-scales in the local universe. We measure the local dimension of the SDSS galaxies on different length-scales and we find that sheets or sheet-like structures are the most prevalent pattern in the cosmic web throughout the entire range of length-scales. The abundance of sheets peaks at 30h1Mpc and they can extend up to a length-scale of 90h1Mpc. Analysing mock catalogues, we find that the sheets are non-existent beyond 30h1Mpc in

the Poisson distributions, and that the straight filaments in the SDSS galaxy distribution can extend only up to a length-scale of 30h1Mpc. Our results indicate that the environment of a galaxy exhibits a gradual transition towards a higher local dimension with increasing length-scales, finally approaching a nearly homogeneous network on large scales. We compare our findings with a semi-analytical galaxy catalogue from the Millennium Run simulation, and these are in fairly good agreement with the observations. We also test the effects of the number density of the sample and the cut-off in the goodness of fit, which shows that the results are nearly independent of these factors. Finally, we apply the method to a set of simulations of the segment Cox process and we find that it can characterize such distributions. This anyalysis has been done in collaboration with Suman Sarkar.

Sanjay Kumar Pandey

Software to compute the energy dependent time-lag and r.m.s from a thermal Comptonized medium

Understanding various observed phenomena in X-ray binaries involves some very challenging and interesting phenomena of astrophysics. Quasi-periodic oscillations (QPO) in low-mass X-ray binaries (LMXB) is one such problem. It is believed that X-ray luminosity of X-ray binaries is due to accretion disc formed by material accreted from a companion star on the copact star such as a netron star. X-ray emission from these binary system vary on wide range of time scales. This variability is in general quantified by computing power density spectra (PDS). Peaked feature of PDS are QPOs. Several models have been proposed to explain the observed kHz QPOs. One such model is proposed by Kumar and Misra in 2014. Using the linearized time-dependent Kompaneets equation, they proposed a method to calculate shape of the r.m.s. as well as time-lag as a function of energy. We have developed a software "COMPT-Time-Lag-RMS" which consists of numerical codes to compute the energy dependent time-lag and r.m.s from a thermal Comptonized medium. The software computes the time and energy dependent time-lag when (a) the seed photon temperature is varied and (b) the coronal heating rate is varied. The energy dependent time-lags are due to light travel timing affects due to Compton scattering in a medium. The results can be compared with observed values, provided the time-lags are interpreted as such. This softwar has been uploaded to $http://astrosat-ssc.iucaa.in/?q=data_and_analysis$. This work has been doen in collaboration with Ranjeev Misra.

Amit Pathak

DFT study on interstellar PAH molecules with aliphatic side groups

Polycyclic aromatic hydrocarbon (PAH) molecules have been long adjudged to contribute to the frequently detected distinct emission features at $3.3, 6.2, 7.7, 8.6, 11.2, and 12.7\mu$m with weaker and blended features distributed in the $3-20\mu$m region. The comparatively weaker 3.4μm emission feature has been attributed to have an aliphatic origin as carrier. PAH with an aliphatic functional group attached to it is one of the proposed potential candidate carriers for the 3.4μm emission band, however, the assignment of carrier is still enigmatic. In this work, we employ density functional theory calculation on a symmetric and compact PAH molecule; coronene (C24H12) with aliphatic side group to investigate any spectral similarities with observed features at $3-4micron\mu m$. The side groups considered in this study are -H (hydrogenated), -CH3 (methyl), -CH2-CH3 (ethyl), and -CH=CH2 (vinyl) functional groups. Considering the possible presence of deuterium (D) in PAHs, we also include D in the aliphatic side group to study the spectral behaviour. We present a detailed analysis of the IR spectra of these molecules and discuss possible astrophysical implications. This work has been in collaboration with Mridusmita Buragohain, Itsuki Sakon, and Takashi Onaka.

Bikash Chandra Paul

Anisotropic compact objects in $f(T)$ gravity with FinchSkea geometry

We study the relativistic solutions of anisotropic compact stars with FinchSkea (FS) metric in $f(T)$ gravity framework. The modified FS geometry is considered to obtain the equation of state (EoS) for different known stellar objects with given mass and radius. The modified Chaplygin gas (MCG) EoS is also considered to obtain stellar objects, as the EoS inside the star is not yet known. The results obtained here are important in the two cases to understand properties of known stars, which are however

not known observationally. The physical features of known stars are analyzed here, and found that compact star formation may be possible with repulsive core. In the case of MCG in $f(T)$ gravity compact stars may be obtained with anisotropic fluid ($p_t > p_r$), with maximum anisotropy at the center of the star, which however, is not found when MCG is absent. This has been studied in collaboration with Anirban Chanda, and Sagar Dey.

NUSTAR and Swift observations of AMXP Swift J1756.92508 during its 2018 outburst

We present here the timing and spectral analysis of the accreting millisecond pulsar (AMXP) SwiftJ1756.92508 during its recent outburst in 2018 using Swift and NuSTAR observations. The simultaneous fitting of the Swift and NuSTAR spectra indicated that the source was in the hard state with a cut-off energy of about 74.58 keV. We also studied in detail the pulse profile of the AMXP and its dependence on energy. The colour-colour diagram of the source was different from those previously reported. We performed phase, and time-resolved spectral analysis using NuSTAR data. Pulse phase-resolved spectra were fitted with a power-law model, and significant changes in the spectral parameters with pulse phase were observed. The orbital phase and time-resolved spectra were fitted with a cut-off power-law model. The column density and photon index obtained from orbital phase spectral analysis were found to show some anti-correlation with the flux. Through time-resolved spectral analysis, we observed that the spectral parameters show positive correlation with each other and with the flux. We did not observe softening of the spectrum with time. No emission lines or Compton bump were observed in the spectrum of the AMXP. This work has been done in collaboration with Binay Rai.

Surajit Paul

Radio relic and the diffuse emission trail discovered in low-mass galaxy cluster Abell 1697

We report the discovery of a putative radio relic, 830 kpc in length, and find towards the outskirts of galaxy cluster Abell 1697 ($z = 0.181$), using the LOFAR Two Meter Sky Survey (LoTSS) at 144 MHz. An X-ray-inferred mass of $M_{500}^{X-ray} = 2.9^{+0.8}_{-0.7} \times 10^{14}$ M$_\odot$ places Abell 1697 among the least massive relic hosts. The relic is also detected at 325 MHz in the Westerbork Northern Sky Survey (WENSS) and at 1.4 GHz in the NRAO VLA Sky Survey (NVSS), with an average spectral index of $\alpha(144, 325, 1400\ \mathrm{MHz}) = -0.98 \pm 0.01$, and magnetic field of $B_{eq} \sim 0.6$ μG. This relic, located in the north-east periphery of the cluster is 300 kpc wide, exhibits a gradual spectral steepening across the width ($\alpha^{1.4\mathrm{GHz}}_{144\mathrm{MHz}}(inj) = -0.70 \pm 0.11$ to $\alpha^{1.4\mathrm{GHz}}_{144\mathrm{MHz}}(edge) = -1.19 \pm 0.15$), as well as indications of a co-spatial X-ray (ROSAT) shock and the radio relic emission. The radio power of the relic is $P_{1.4GHz} = 8.5 \pm 1.1 \times 10^{23}$ W Hz^{-1}, which is found to be in good agreement with the expected empirical correlation between the radio power and largest linear size (LLS) of relics. The relic is trailed by extended (790 × 550 kpc) diffuse radio emission towards the cluster centre, which is likely an ultra-steep spectrum ($\alpha^{1.4\mathrm{GHz}}_{144\mathrm{MHz}} < -1.84$) radio source. This structure is also found to be older by at least 190 Myrs, has a very low surface brightness of 0.3 μJy arcsec^{-2} and magnetic field $B_{eq} \sim 0.8$ μG, similar to that of a radio phoenix. Finally, we discuss the possible mechanisms responsible for the relic and the trailing diffuse radio emission, invoking re-acceleration due to wake turbulence, as well as the revival of fossil electrons in the remnant radio lobes of active galactic nuclei (AGN) by the cluster merger shocks. This work has been done in collaboration with Sameer Salunkhe, Satish Sonkamble, Prateek Gupta, Tony Mroczkowski, and Somak Raychaudhury.

Low-frequency radio study of MACS clusters using the GMRT at 610 and 235 MHz

Studies have shown that mergers of massive galaxy clusters produce shocks and turbulence in the intracluster medium, the possible event that creates radio relics, as well as the radio halos. Here, we present GMRT dual-band (235 and 610 MHz) radio observations of four such clusters from the MAssive Cluster Survey (MACS) catalogue. We report the discovery of a very faint, diffuse, elongated radio source with a projected size of about 0.5 Mpc in cluster MACSJ0152.5-2852. We also confirm the presence of a radio relic-like source (about 0.4 Mpc, previously reported at 325 MHz) in MACSJ0025.4-1222 cluster. Proposed relics in both these clusters are found apparently inside the virial radius instead of their usual peripheral location, while no radio halos are detected. These high-redshift clusters ($z = 0.584$ and 0.413) are among

the earliest merging systems detected with cluster radio emissions. In MACSJ1931-2635 cluster, we found a radio mini-halo and an interesting highly bent pair of radio jets. Further, we present here a maiden study of low frequency (GMRT 235 and 610 MHz) spectral and morphological signatures of a previously known radio cluster MACSJ0014.3-3022 (Abell 2744). This cluster hosts a relatively flat spectrum ($\alpha_{235}^{610} \sim -1.15$), giant ($\sim$ 1.6 Mpc each) halo-relic structure and a close-by high-speed ($1769\pm^{148}_{359}$ km s^{-1}) merger-shock ($\mathcal{M} = 2.02\pm^{0.17}_{0.41}$) originated from a possible second merger in the cluster. This work has been done in collaboration with Sameer Salunkhe, Abhirup Datta, and Huib Intema.

Ananta Charan Pradhan

A catalogue of 108 extended planetary nebulae observed by GALEX

We present the ultraviolet (UV) imaging observation of planetary nebulae (PNe) using archival data of Galaxy Evolution Explorer (GALEX). We found 358 PNe detected by GALEX in near-UV (NUV). We have compiled a catalogue of 108 extended PNe with sizes greater than 8″ and provided the angular diameters for all the 108 extended PNe in NUV and 28 in FUV from the GALEX images considering 3σ surface brightness level above the background. Of the 108 PNe, 74 are elliptical, 24 are circular and 10 are bipolar in NUV with most being larger in the UV than in the radio, Hα or optical. We derived luminosities for 33 PNe in FUV (LFUV) and 89 PNe in NUV (LNUV) and found that most of the sources are very bright in UV. The FUV emission of the GALEX band includes contribution from prominent emission lines N IV] (1487 Å), C IV (1550 Å), and O III] (1661 Å) whereas the NUV emission includes C III] (1907 Å) and C II (2325 Å) for PNe of all excitation classes. The other emission lines seen in low excitation PNe are O IV] (1403 Å) and N III (1892 Å) in FUV, and O II (2470 Å) and Mg II (2830 Å) in NUV. Similarly the emission lines O V (1371 Å) and He II (1666 Å) strongly contribute in FUV for high and medium excitation PNe but not for low excitation PNe. A mixture of other emission lines seen in all excitation PNe. We have also provided images of 34 PNe in NUV and 9 PNe in FUV. This work has been done in collaboration with Swayamtrupta Panda, Mudumba Parthasarathy, Jayant Murthy, and Devendra K. Ojha.

Study of atomic spectroscopy and hyperfine structure of francium (Fr) isotopes using relativistic Fock space multireference coupled cluster method

The electronic structure and properties of ^{210}Fr, ^{212}Fr, ^{221}Fr and ^{223}Fr isotopes have been studied using the relativistic Fock space multireference coupled-cluster method. By employing this method, we have determined the magnetic hyperfine constants for the loweset multiplets of francium (Fr) isotopes with Dirac-Fock orbitals. We have provided the data for the ionization potentials and excitation energies for the Fr isotopes. The discrepancies between our calculated values and the corresponding measured experimental values are less than 2% (for energy). In addition, we also report the transition probabilities and oscillator strengths for the various allowed E1 transitions of Fr. The estimated properties are in very good agreement with the available experimental values. This work has been done in collaboration with Madhulita Das.

Anirudh Pradhan

Friedmann-Robertson-Walker accelerating Universe with interactive dark energy

In this work, we study a model based on the cosmological principle which exhibits a transition from deceleration to acceleration. We consider baryonic matter, dark energy, and "curvature" energy. Both baryonic matter and dark energy (DE) have variable equations of state. It is assumed that dark energy interacts with and transforms energy to baryonic *matter*. An FRW universe filled with two fluids has been discussed. The model is shown to satisfy current observational constraints. This universe is at present in a phantom phase after passing through a quintessence phase in the past. Various cosmological parameters regarding the accelerating universe have been presented. The evolution of DE, Hubble, and deceleration parameters, etc. have been described with the aid of figures. Our theoretical results have been compared with the SNe Ia related union 2.1 compilation 581 data, and we have observed that our derived model is in good agreement with current observational constraints. We have also explored the physical properties of the model. This work has been done in collaboration with Gopi Kant Goswami and Aroonkumar Beesham

Anisotropic MHRDE model in BD theory of gravitation

In this work, in the framework of the Brans-Dicke gravitation theory, we propose to study the spatially homogeneous, anisotropic and axially symmetric model filled with dark matter and dark energy. Here, we consider modified holographic Ricci dark energy proposed by Chen and Jing as a feasible state of darkness. To achieve a solution, we consider the time-dependent deceleration parameter, which contributes to the average scale factor of $a(t) = exp(\frac{1}{\beta}\sqrt{2\beta t + \alpha})$, where $\alpha > 0$ and $\beta > 0$ are arbitrary constants. We have derived field equations of Brans-Dicke theory of gravitation with the help of an axially symmetric anisotropic Bianchi-type spacetime. We have determined the cosmological parameters, namely, deceleration parameter, matter energy density, anisotropic dark energy density, BD scalar field skewness parameter, EoS parameter, and jerk parameter. Here, the various phenomena like the Big Bang, expanding the universe, and shift from anisotropy to isotropy are observed in the model. A comprehensive physical debate of these dynamic parameters is provided through a graphical representation. We observe that it is a quintessence model that exhibits a smooth transition from decelerated stage to an accelerated phase of the universe. This situation is in complete agreement with the modern cosmology scenario. Some physical and geometric behaviours are also discussed and discovered to be in excellent agreement with SNe Ia Supernova's latest observations. This work has been done in collaboration with Archana Dixit, and Shilpi Singhal

Prince P.R.

Investigations into solar flare effects using wavelet-based local intermittency measure

The present study analyzes the efficiency of local intermittency measure based on wavelet transforms in identifying solar flare effects on magnetograms. If we observe the flare-time features in geomagnetic components, most often, disturbances associated with other solar phenomena will enhance or mask the solar flare signatures. Similarly, diurnal and high-latitude geomagnetic variabilities will suppress solar flare effects on magnetograms. The measurements of amplitudes taken directly from temporal variations of weak geomagnetic components have certain limitations regarding the identification of the proper base and peak values from which the deviation due to solar flare has to be measured. In such situations, local intermittency measure based on cross-wavelet analysis can be employed, which could remarkably identify the flare effects, even if the signatures are weak or masked by other disturbance effects. The present study shows that local intermittency measure based on wavelet analysis could act as an alternate quantification technique for analyzing solar flare effects on geomagnetic activity. This work has been done in collaboration with Sumesh Gopinath.

A comparison of machine-learning techniques for the prediction of the auroral electrojet index

The modern machine-learning models are a section of artificially intelligent machines used to implement complex models, which can learn and improve from experience with respect to certain class of jobs, without being specifically programmed. In the present analysis, a comparative study is made of the popular machine-learning techniques regarding the prediction of auroral activity as reflected by the auroral electrojet AE index during geomagnetically disturbed periods. The study also explores the suitability of the online sequential version of the best machine-learning algorithm, which has the potential for real-time forecast of the AE index from short-time input datasets with extremely fast convergence than batch-training methods. The study discusses the need for the correct choice of the input dataset, that can be used for predicting the AE index from several combinations of input datasets which include coupling functions, geomagnetic indices and solar wind parameters. The study reveals that extreme learning machine and its online sequential version are promising models, which could predict the AE index extremely fast with a high degree of accuracy even during disturbance periods. The study also shows that the choice of the polar cap PC index as an input parameter is extremely important for an accurate prediction of the AE index. This work has been done in collaboration with Sumesh Gopinath.

Anisur Rahaman

Chiral Schwinger model with Faddeevian anomaly and its BRST quantization

We consider chiral Schwinger model with Faddeevian anomaly, and carry out the quantization of

both the gauge-invariant and non-invariant version-Theoretical spectra have been determined both in the Lagrangian and Hamiltonian formulation and a necessary correlation between these two is made. BRST quantization using BFV formalism has been executed, which shows spontaneous appearance of Wess-Zumino term during the process of quantization. The gauge invariant version of this model in the extended phase space is found to map onto the physical phase space with the appropriate gauge fixing condition. This work has been done in collaboratio with Sanjib Ghosal.

Role of Faddeevian anomaly in the s-wave scattering of chiral Fermion off dilaton black holes towards preservation of information

It was found that s-wave scattering of chiral Fermion off dilaton black-hole when studied with a model generated from the chiral Schwinger model with standard Jackiw-Rajaraman type of anomaly provided information non-preserving result. However, this scattering problem when studied with a model generated from chiral Schwinger model with generalized Faddeevian type of anomaly rendered information preserving result and it had well agreement with Hawking's revised proposal related to information loss. A minute and equitable investigation in detail has been carried out here to show how Faddeevian type of anomaly scores over the Jackiw-Rajaraman type of anomaly in connection with the s-wave scattering of chiral fermion of dilaton black-hole related to preservation of information.

Farook Rahaman

Gravitational collapse of an interacting vacuum energy density with an anisotropic fluid

We investigate the effects of anisotropic pressure on the gravitational collapse of spherically symmetric, gravitational bound objects. The concept of a pressure anisotropy in stellar models is produced by a large set of physical phenomena in high density regimes. We consider a gravitational collapse process of the anisotropic fluid interacting with a growing vacuum energy density. We consider the full general-relativistic treatment of this problem, and obtain exact solutions for various forms of the equation of state $(k, l) : p_t = k\rho$ and $p_r = l\rho, (l+2k) < -1$ connecting the tangential and radial pressures respectively. This work has been done in collaboration with Harsat Hussain Shah, Amna Ali, and Sabiruddin Molla.

Einstein's cluster mimicking compact star in the teleparallel equivalent of general relativity

The Teleparallel Gravity (TEGR) is an alternative formulation of gravity which uses tetrads as the dynamical variables. First, we develop the Einstein clusters in TEGR field equations using effective energy-momentum tensor for diagonal as well as off-diagonal tetrad. We then study the clusters in modified $f(T)$ gravity for anisotropic fluid distribution. We further study the solution without net electric charge and then for charged solution. For charge parameter $k \to 0$, the charged solution reduces to neutral one. Our calculations show that when charge increases, the stiffness of the EoS also increases. This is due to increase in adiabatic index and sound speed approaching speed of light. When the charge increases beyond a certain limit ($0 \leq k \leq 1.3 \times 10^{-5}$ and $0 \leq k \leq 1 \times 10^{-6}$), the compactness parameter crosses the Buchdahl limit, i.e., $2M/R > 8/9$, and the solution starts violating the causality condition. We test the Tolman-Oppenheimer-Volkoff (TOV) limit for such compact objects. We analyze the static stability criterion of the Einstein clusters for both charged and uncharged case, and the stability of such compact objects is enhanced by the presence of some net electric charge. In addition, we present and discuss the energy conditions, causality condition and the adiabatic index close to the stability limit. After analyzing these problems, we conclude that the Einstein clusters do exists only if $f(T)$ is a linear function of the torsion scalar T, that is, in the case of Teleparallel equivalent of General Relativity. Finally, we compare our solution for pure general relativity. As a result, we concluded that the Einstein cluster solution do exist in pure GR, however, physically unfit to mimic compact stars. We have also extend our findings by assuming the diagonal or off-diagonal tetrad and specific case of $f(T)$. In such models, Einstein's cluster solutions do exist, however, can't mimic the properties of a compact star. This work has been done in collaboration with Ksh. Newton Singh, and Ayan Banerjee.

Shantanu Rastogi

Seasonal heterogeneity in aerosol optical properties over the subtropical humid region of northern India

First-ever measurements and study of aerosol optical properties from a subtropical humid region of the eastern part of the central Indo-Gangetic Plain (IGP), Gorakhpur (26.75N, 83.38E, 85m amsl) is presented. Four years, March 2014-February 2018, of columnar aerosol optical measurements, using a multi-wavelength solar radiometer (MWR), are analyzed to examine temporal and seasonal heterogeneity in aerosol optical properties, and to ascertain aerosol types over the study region along with their seasonal contribution. Average columnar aerosol optical depth at 500 nm (AOD500) is 0.65 ± 0.27, with highest seasonal mean (0.73 ± 0.30) during pre-monsoon (PM) and lowest seasonal mean (0.59 ± 0.25) during monsoon (M) season. During PM season, more than 50% of AOD500 values are greater than 0.7 indicating high aerosol loading over the study region. Large variability in Angstrom exponent (α) and atmospheric turbidity (β) from 0.12 to 2.26 and 0.05 to 1.34, with mean value of 0.92 ± 0.27 and 0.37 ± 0.14, respectively, indicates heterogeneous aerosol emission sources and turbid atmosphere over the study region. Higher α (>1) during post-monsoon (PoM) and winter (W) seasons indicate predominance of fine mode aerosols, whereas lower α (<0.7) during PM season indicate prevalence of coarser mode aerosols, over the study region. Aerosols of urban/industrial and biomass burning origins (UB) have maximum contribution during PoM (71.4%) and W (56.2%) seasons, while more than 25% of mixed type (MT) aerosols are observed throughout the study period with maximum contribution observed during M (63%) season. AOD retrieved from MWR and that from MODerate-resolution Imaging Spectroradiometer (MODIS) compare reasonably well with a correlation coefficient of 0.66. This work has been done in collaboration with Prayagraj Singh, Aditya Vaishya, and Suresh Babu.

C. D. Ravikumar

Co-evolution of nuclear rings, bars and the central intensity ratio of their host galaxies

We study a sample of 13 early-type spiral galaxies hosting nuclear rings and report remarkable correlations between the properties of the nuclear rings, and the newly discoverd central intensity ratio (CIR) of their host galaxies. The CIR is a purely photometric quantity involving intensities of light within the central 1.5 and 3 arcsec region of a galaxy, and is found to be a vital parameter in galaxy evolution, as it shares strong correlations with many structural and dynamical properties of early-type galaxies, including mass of the central supermassive black hole (SMBH). They observe strong correlations of CIR with the relative sizes of nuclear rings and ring cluster surface densities, which suggest reduced star formation in the centres of galaxies hosting small and dense nuclear rings. There is signicant connection observed between the CIR and bar strengths. In addition, we observe that the CIR is closely related with the integrated properties of the stellar population in the nuclear rings, associating the rings hosting older and less massive star clusters with low values of CIR. Thus, the CIR serves as a crucial parameter in unfolding the coupled evolution of bars and rings in galaxies. This study has been done in collaboration with S. Aswathy.

Saibal Ray

Study on charged strange stars in f (R,T) gravity

We investigate the effects of the modified $f(R,\mathcal{T})$ gravity on the charged quark stars for the standard choice of $f(R,\mathcal{T}) = R + 2\chi\mathcal{T}$. These types of stars are supposed to be made of strange quark matter (SQM), whose distribution is governed by the phenomenological MIT bag EoS as $p = 1/3(\rho - 4B)$, where B is the bag constant, while the form of charge distribution is chosen to be $q\,(r) = Q\,(r/R)^3 = \alpha r^3$ with α as a constant. We derive the values of the unknown parameters by matching the interior spacetime to the exterior Reissner-Nordström metric followed by the appropriate choice of the values of the parameters χ and α. The study under the $f(R,\mathcal{T})$ gravity reveals that besides SQM, a new kind of matter distribution originates due to the interaction between the matter and the geometric term, while the modification of the Tolman-Oppenheimer-Volkoff (TOV) equation invokes the presence of a new force F_c. The accumulation of the electric charge distribution reaches its maximum at the surface, and the predicted values of the corresponding electric charge and electric field are in the order of 10^{19-20} C and 10^{21-22} V/cm, respectively. To ex-

amine the physical validity of the solutions, we perform tests of energy conditions, stability against the equilibrium of forces, adiabatic index, etc., and find that the proposed $f(R, \mathcal{T})$ model survives from all these critical tests, and hence, not only can explain the non-singular charged strange stars but also viability of the supermassive compact stellar objects having their masses beyond the maximum mass limit for the compact stars in the standard scenario. Therefore, the present $f(R, \mathcal{T})$ gravity model seems promising regarding existence of several exotic astrophysical objects, like super-Chandrasekhar white dwarfs, massive pulsars, and even magnetars, which remain unexplained in the framework of general relativity (GR). This work has been studied in collaboration with Debabrata Deb, Sergei V. Ketov, and Maxim Khlopove.

Inflation in anisotropic brane universe using tachyon field

Cosmological solution to the gravitational field equations in the generalized Randall-Sundrum model for an anisotropic brane with Bianchi I geometry and perfect fluid as matter sources has been considered. The matter on the brane is described by a tachyonic field. The solution admits inflationary era, and at a later epoch the anisotropy of the universe washes out. We obtain two classes of cosmological scenario, in the first case universe evolves from singularity, and in the second case universe expands without singularity. This work has been done in collaboration with Rikpratik Sengupta.

Prabir Rudra

Dynamical system analysis of generalized energy-momentum-squared gravity

In this work, we have investigated the dynamics of a recent modification to the general theory of relativity, the energy-momentum squared gravity model $f(R, \mathbf{T^2})$, where R represents the scalar curvature and $\mathbf{T^2}$ the square of the energy-momentum tensor. By using dynamical system analysis for various types of gravity functions, we have studied the structure of the phase space and the physical implications of the energy–momentum squared coupling. In the first case of functional where $f(R, \mathbf{T^2}) = f_0 R^n (\mathbf{T^2})^m$, with f_0 constant, we have shown that the phase space structure has a reduced complexity, with a high sensitivity to the values of m and n parameters. Depending on the values of m and n parameters, the model exhibits various cosmological epochs, corresponding to matter eras, solutions associated to an accelerated expansion, or decelerated periods. The second model studied corresponds to the $f(R, \mathbf{T^2}) = \alpha R^n + \beta(\mathbf{T^2})^m$ form with α, β constant parameters. In this case, a richer phase space structure is obtained, which can recover different cosmological scenarios, associated to matter eras, deSitter solutions, and dark energy epochs. Hence, this model represents an interesting cosmological model which can explain the current evolution of the universe and the emergence of the accelerated expansion as a geometrical consequence. This work has been done in collaboration with Sebastian Bahamonde, and Mihai Marciu.

Gravitational baryogenesis in Horava-Lifshitz gravity

In this work, we intend to address the matter-antimatter asymmetry via the gravitational baryogenesis mechanism in the background of a quantum theory of gravity. We investigate this mechanism under the framework of Horava-Lifshitz gravity. We compute the baryon-to-entropy ratio in the chosen framework and investigate its physical viability against the observational bounds. We also conduct the above study for various sources of matter like scalar field and Chaplygin gas as specific examples. We infer that quantum corrections from the background geometry will lead to interesting results. This work has been done in collaboration with Sayani Maity.

Sanjay K. Sahay

An overview of deep learning architecture of deep neural networks and autoencoders

Recently, deep learning has shown great progress in multiple fields, but to perform optimally, it requires the adjustment of various architectural features and hyper-parameters. Moreover, deep learning could be used with multiple varieties of architecture aimed at different objectives, e.g., autoencoders are popular for un-supervised learning applications for reducing the dimensionality of the dataset. Similarly, deep neural networks are popular for supervised learning applications viz., classification, regression, etc. Besides the type of deep learning architecture, some other decision criteria and parameter selection decisions are required for determining the number of layers, size of each layer,

activation and loss functions for different layers, optimizer algorithm, regularization, etc. Thus, this work aims to cover different choices available under each of these major and minor decision criteria for building a neural network, and training it optimally to effectively serve the objectives, e.g., malware detection, natural language processing, image recognition, etc. This work has been done in collaboration with Mohit Sewak, and Hemant Rathore

Secure and energy-efficient key-agreement protocol for multi-server architecture

Authentication schemes are practiced globally to verify the legitimacy of users and servers for the exchange of data in different facilities. Generally, the server verifies a user to provide resources for different purposes. But due to the large network system, the authentication process has become complex and therefore, time-to-time different authentication protocols have been proposed for the multi-server architecture. However, most of the protocols are vulnerable to various security attacks and their performance is not efficient. In this work, we propose a secure and energy-efficient remote user authentication protocol for multi-server systems. The results show that the proposed protocol is comparatively ∼44 % more efficient and needs ∼38 % less communication cost. We also demonstrate that with only two-factor authentication, the proposed protocol is more secure from the earlier related authentication schemes. This work has been done in collaboration with Trupil Limbasiya

Sandeep Sahijpal

Evolution of the galaxy and the origin of the solar system

We have developed galactic chemical evolution (GCE) models of the short-lived radio nuclides (SLRs), 26Al, 36Cl, 41Ca, 53Mn, and 60Fe, across the entire Milky Way galaxy. The objective was to understand the spatial and temporal distribution of the SLRs in the galaxy. Based on the formulation, we provide a novel method to amalgamate the origin of the solar system with the gradual evolution of the galaxy along with a self-consistent origin of SLRs. We have explored the possibility of the birth of the solar system in an environment where one of the stellar clusters formed 25 Myr earlier. The decaying 53Mn and 60Fe remnants from the evolved massive stars from the cluster probably contaminated the local medium associated with the presolar molecular cloud. A Wolf-Rayet wind from a distant massive star, belonging to a distinct cluster, probably contributed, 26Al (and 41Ca) to the presolar cloud. This work has been done in collaboration with Tejpreet Kaur.

Thermodynamics of dust condensation in astrophysical environments

We have performed comprehensive thermodynamical calculations of the condensation of dust grains around Wolf-Rayet (WR). A novel numerical code has been developed for dust condensation. It was found that mostly C (graphite), TiC, SiC, AlN, CaS and Fe-metal were condensed in WR winds. The results indicate that dust grains that are condensed in the WC phase may make a substantial contribution of carbon-rich dust grains to the interstellar medium. We have also performed a comprehensive correlated study of the thermodynamics condensation of dust grains in distinct stellar environments with the galactic chemical evolution of the Milky Way galaxy. Based on the elemental composition of the evolving Galaxy, the relative abundances of the major constituents of interstellar dust are assessed. The supernovae SN Ia are predicted as the most prominent sources of Fe-dust mass, the supernovae SN II + Ib/c produces oxides and silicate dust mass, and the AGB stars contributes to carbonaceous dust mass. This is studied in collaboration with Anuj Gupta.

Biplob Sarkar

Effect of magnetic flux advection on the dynamics of shock in accretion flow around a rotating black hole

We investigate the dynamical behaviour of a magnetized, dissipative, accretion flow around a rapidly rotating black hole. We solve the magnetohydrodynamic equations, and calculate the transonic accretion solutions which may contain discontinuous shock transitions. We investigate the effect of $\zeta-$ parameter (parametrizing the radial variation of the toroidal magnetic flux advection rate) on the dynamical behaviour of shocks. For a rapidly rotating black hole and for fixed injection parameters at the outer edge, we show that stationary shocks are sustained in the global magnetized accretion solutions for a wide range of ζ and accretion rate ($\dot{m}$).

To investigate the observational implications, we consider dissipative shocks and estimate the maximum accessible energy from the post-shock corona (PSC) for nine stellar mass black hole candidates. We compare this with the observed radio jet kinetic power reported in the literature, whenever available. We find close agreement between the estimated values from our model with those reported in the literature This work has been done in collaboration with Anjali Rao.

Rathin Sarma and **Amit Pathak**

NuSTAR observation of Ark 564 reveals the variation of coronal temperature with flux

The hard X-ray spectral index of some AGNs has been observed to steepen with the source flux. This has been interpreted in a thermal Comptonization scenario, where an increase in the soft flux decreases the temperature of the corona, leading to steepening of the photon index. However, the variation of the coronal temperature with flux has been difficult to measure due to the presence of complex reflection component in the hard X-rays and the lack of high-quality data at that energy band. Recently, a 200 ks *NuSTAR* observation of Ark 564 in 3–50 keV band, revealed the presence of one of the coolest coronae with temperature $kT_e \sim 15$ keV in the time-averaged spectrum. Here, we re-analyse the data and examined the spectra in four flux levels. Our analysis shows that the coronal temperature decreased from ~ 17 to ~ 14 keV as the flux increased. The high energy photon index $\Gamma \sim 2.3$ varied by less than 0.1, implying that the optical depth of the corona increased by about 10% as the flux increased. This first reporting of coronal temperature variation with flux shows that further long observation by *NuSTAR* of this and other sources would shed light on the geometry and dynamics of the inner regions of the accretion flow. This work is done in collaboration with Samuzal Barua, Vadakkumthani Jithesh, Ranjeev Misra, and Gulab C. Dewangan.

Asoke Kumar Sen

Spectroscopic survey of H-alpha emission line stars associated with bright-rimmed clouds

The results of a spectroscopic survey of H_α emission line stars associated with fourteen bright rimmed clouds are presented. Slit-less optical spectroscopy was carried out with the IUCAA Girawali Obervatory 2 m telescope, and IUCAA Faint Object Spectrograph and Camera (IFOSC). H_α emission line was detected from 173 objects. Among them, 85 objects have a strong H_α emission line with its equivalent width larger than 10 A. Those are classical T Tauri stars. 52 objects have a weak H_α emission line with its equivalent width less than 10 A and do not show intrinsic near-infrared excess. Those are weak-line T Tauri stars. On the other hand, 36 objects have a weak H_α emission line ($< 10A$), although they show intrinsic near-infrared excess. Such objects are not common in low-mass star forming regions. Those are misfits of the general concept on formation process of a low-mass star, in which it evolves from a classical T Tauri star to a weak-line T Tauri star. Those might be weak-line T Tauri stars with a flared disk, in which gas is heated by ultraviolet radiation from a nearby early-type star. Alternatively, we propose pre-transitional disk objects as their evolutional stage. This work has been done in collaboration with Kensuke Hosoya, Yoichi Itoh, Yumiko Oasa, and Ranjan Gupta.

Photometry and colour index of Comet 67P/Churyumov-Gerasimenko on 2015 December 12

Comet 67P/Churyumov-Gerasimenko (hereafter, 67P) was observed on 12 December 2015, from 2 m Himalayan Chandra Telescope in India in photometry to study its dust properties, using Bessell R and I filters. We study the photometric images to highlight coma structures and jets. The radial decrease in intensity in the different coma structures are compared to the azimuthally integrated intensities. The observations of the slopes show a quasi-steady-state coma to an optocentric distance of about 20,000 km. The change in the slopes in the structures indicates changing properties of the dust particles and/or change in their local size distributions. Comparison of the radial decrease in the two wavelengths suggests a change in the local colour-index. Based on the absolute photometry carried out in the present work, we calculate the reddening of the comet dust, which helps to characterize variations in the size and the materials of the particles. The colour-index is calculated for different apertures and regions in the coma (0.40 $\pm$ 0.07 mag) for a 22,000 diameter aperture. A

colour map is constructed showing the variation of the colour-index through the coma. Changes appear at the transition between the coma and the tail with a low colour-index (< 0.3 mag) close to the optocentre and further away increasing up in the tail direction (about 0.45 mag at 10 000 km). We interpret these changes in terms of dust properties, and we compare our results to other remote observations of 67P including in situ Rosetta observations This work has been done in collaboration with Edith Hadamcik, Robert Botet, Jeremie Lasue, Saumyadeep Roy Choudhury, and Ranjan Gupta.

T. R. Seshadri

Probing magnetic field in high-redshift galaxies using background quasars

We probed the magnetic fields in high-redshift galaxies using excess extragalactic contribution to residual rotation measure (rrm) for quasar sightlines with intervening Mg II absorbers. For this purpose, archival data for 1,132 quasars have been used and the spread in the rrm has been computed. The lines-of-sight to the quasar could pass through intermediate galaxies. If this happens, one also expected to see an absorption in MgII. If there are more than one such intermediate systems, one expects such absorption features at different redshifts. We have found the spread to be 17.1±0.7 rad m^{-2} for 352 sightlines having Mg II intervening absorbers in comparison to its value of 15.1±0.6 rad m^{-2} for 780 sightlines without such absorbers, resulting in an excess broadening (σ^{ex}_{rrm}) of 8.0±1.9 rad m^{-2} among these two subsamples. This value of σ^{ex}_{rrm}, has allowed us to constrain the average strength of magnetic field (rest frame) in high redshift galaxies responsible for these Mg II absorbers, to be $\sim 1.3 \pm 0.3 \mu G$ at a median redshift of 0.92. A similar analysis was done on subsample split based on the radio spectral index, α, (with $F_\nu \propto \nu^\alpha$). The spectral index α was found to be greater than or equal to -0.3 for 315 sources and ≤ -0.7 for 476 sources. The former shows a significant σ^{ex}_{rrm} (at 3.5σ level) and is absent in latter. An anti-correlation found between the σ^{md}_{rrm} and percentage polarisation (p) with similar Pearson correlation of -0.62 and -0.87 for subsample with and without Mg II, respectively, suggests main contribution for decrements in the p value to be intrinsic to the local environment of quasars. This work has been done in collaboration with Sunil Malik, and Hum Chand.

Constraining the spectral index of density perturbations from primordial black holes

Primordial Black Holes (PBHs) could be formed due to the collapse of the inhomogeneities that were generated during inflation in the early universe. Their evaporation can lead to energy injection in the universe. By using the current results of the baryon-photon ratio obtained from BBN and CMB observations, we impose constraints on the spectral index of perturbations on those small scales that cannot be estimated through CMB anisotropy and CMB distortions. The masses of the PBHs constrained in this study lie in the range of 10^9 and 10^{11}g, which corresponds to those PBHs whose maximal evaporation took place during the redshifts $10^6 < z < 10^9$. It is shown that the upper bound on the scalar spectral index, n_s can be constrained for a given threshold value, $\zeta_{\rm th}$, of the curvature perturbations for PBHs formation. Using Planck results, We obtained constraints on the scalar spectral index, n_s to be less than 1.309 for $\zeta_{\rm th} = 0.7$ and $n_s < 1.334$ for $\zeta_{\rm th} = 1.2$, respectively. We have also estimated the the density fraction that has contributed to the formation of PBH. This work is carried out in collaboration with Gaveshna Gupta, and Ramkishor Sharma.

Mohit Kumar Sharma

Transfer of radiation in the formic acid - A precursor for amino acids

Formic acid (HCOOH), a simplest carboxylic acid, has great importance as it is a precursor for amino acids (constituents of life). It has two rotameric isomers: trans-HCOOH and cis-HCOOH, each of which lies in a plane due to the delocalization of π-electrons over the heavy atom chain. In each of the isomers, the electric dipole moment is aligned such that there are both a and b type rotational transitions. Further, the energy levels in each type of transitions can be classified into two groups. Thus, there are 8 groups in which the rotational transitions of formic acid may be classified. The trans-HCOOH is detected in Sgr B2, cold dark cloud L134N, Sgr A, comet Hale-Bopp, Orion KL, W51, IRAS 16293-2422 through its a-type transitions. Because of very small value of b-component of electric dipole moment, the b-type transitions of trans-

HCOOH may not be detected. To our knowledge, no transitions of cis-HCOOH are yet detected in the interstellar medium, though a and b components of its electric dipole moment are quite large.

Using spectroscopic data of trans-HCOOH and cis-HCOOH, we have calculated energies of 100 rotational levels for each of the 8 groups, and the radiative transition probabilities (Einstein A and B coefficients) for radiative transitions between the levels. Since the rate coefficients for collisional transitions between the levels are not available, by using the scaled values for them along with the radiative transition probabilities, we have solved a set of 100 statistical equilibrium equations coupled with the equations of radiative transfer for each group. We have investigated intensities of 16 observed a-type transitions and 12 b-type transitions of trans-HCOOH. We have also found six transitions, $1_{10}-1_{11}$ (1.405 GHz), $2_{12}-3_{03}$ (7.545 GHz), $3_{12}-3_{03}$ (79.744 GHz), $3_{21}-3_{12}$ (222.287 GHz), $1_{11}-2_{02}$ (30.843 GHz) and $4_{13}-4_{04}$ (82.740 GHz) of cis-HCOOH showing anomalous absorption and nine transitions $4_{14}-3_{13}$ (85.042 GHz), $5_{15}-4_{14}$ (106.266 GHz), $3_{03}-2_{02}$ (65.840 GHz), $4_{04}-3_{03}$ (87.694 GHz), $5_{05}-4_{04}$ (109.470 GHz), $5_{05}-4_{14}$ (40.778 GHz), $7_{07}-6_{16}$ (90.910 GHz), $4_{04}-3_{13}$ (16.350 GHz) and $6_{06}-5_{15}$ (65.661 GHz) of cis-HCOOH showing emission feature. These transitions of cis-HCOOH in addition to those of trans-HCOOH may help in the identification of HCOOH in a cosmic object.

LVG analysis of amidogen radical (NH_2) found in interstellar medium and in cometary material

Amidogen (NH_2), a b-type asymmetric top molecule with electric dipole moment 1.82 ± 0.05 Debye, is detected in Sgr B2, in high-mass star-forming regions W31C (G10.6-0.4), W49N (G43.2-0.1), W51 (G49.5-0.4), G34.3+0.1, and in several comets. Because of two hydrogen atoms, each with nuclear spin 1/2, its rotational energy levels can be classified into ortho and para groups. We have not considered for fine structure splitting and hyperfine structure splitting of rotational levels. For 15 rotational levels in the ground vibrational state, having energy up to 400 cm^{-1}, for each specie, the energies of rotational levels, and Einstein A and B coefficients for radiative transitions between the levels are calculated, using accurate values of spectroscopic data. These radiative transition probabilities along with the collisional rate coefficients (obtained from a scaling law) are employed as input parameters for solving a set of statistical equilibrium equations coupled with the equations of radiative transfer for each group. Several emission lines produced by amidogen are found. For each specie of NH_2, we have considered some strongest emission lines along with the observed one, which may help for identification of NH_2 in the interstellar medium (ISM) and in the cometary material.

Ranjan Sharma

Revisiting Vaidya-Tikekar stellar model in the linear regime

In this work, we have developed a new class of solutions describing the interior of a spherically symmetric static star composed of an anisotropic matter distribution by revisiting the Vaidya and Tikekar stellar model in the linear regime. The Vaidya and Tikekar ansatz is characterized by a geometric feature that time t = constant hypersurface of the associated spacetime when embedded in a 4-Euclidean space becomes spheroidal. Physical viability of the subsequent stellar model has been analyzed. Impact of the curvature parameter K of the Vaidya and Tikekar ansatz, which characterizes the departure from spherical geometry, on the mass-radius relationship of the star has been probed. In the context of density dependent bag model for strange stars, a corelation between the curvature parameter K, the bag constant B, the mass M and the radius R of some of the well known strange star candidates like Her X-1, RX J1856-37 and SAX J1808.4 have been investigated. The possibility of fine-tuning these parameter based on observational data has been outlined. This work is done in collaboration with Shyam Das, Megan Govender, and Dishant M. Pandya.

Anisotropic generalization of Vaidya-Tikekar superdense stars

Exact solutions to Einstein field equations corresponding to various astrophysical systems and their physical interpretation are of prime significance for our understanding of gross physical features of relativistic compact objects. In this work, the authors have developed a new class of solutions describing the interior of a superdense relativistic star composed of an anisotropic matter distribution with spheroidal spatial hypersurface. Thus, the new class of solutions may be treated as an anisotropic

generalization of the Vaidya and Tikekar superdense stellar model. In this treatment, the Einstein field equations have been solved in terms of hypergeometric functions. Subsequently, for particular parameter choices, the solutions have been expressed in terms of elementary functions. In this treatment, stellar systems with is tropic pressure can be generated in the limit of vanishing anisotropy. Consequently, some of the well known superdense star models, which are isotropic and have specific spheroidal geometries have been regained. The impact of anisotropy on the gross physical properties of a compact star has been analyzed. This work is done in collaboration with S. Thirukkanesh, and Sunil D. Maharaj.

Gyan Prakash Singh

Variable Chaplygin gas cosmologies in $f(R,T)$ gravity with particle creation

A flat FLRW cosmological model with perfect fluid comprising of variable Chaplygin gas has been studied in the context of $f(R,T)$ gravity with particle creation. The solutions of the modified field equations are obtained through three different considered form of scale factors. The effective pressure is negative throughout the evolution of universe, which leads to accelerated expansion of the universe. In addition to that, we have also discussed the importance of particle creation pressure on the cosmological parameters, energy conditions and state-finder diagnostic parameters. It is noticed that, the time evolution of source function yields almost constant particle production at late times.This work has been done in collaboration with Nikhil Hulke, Binaya K. Bishi, and Ashutosh Singh.

Harinder Pal Singh

The tale of the Milky Way Globular Cluster NGC 6362 – I. The orbit and its possible extended star debris features as revealed by Gaia DR2

We report the identification of possible extended star debris candidates beyond the cluster tidal radius of NGC 6362 based on the second *Gaia* data release (*Gaia* DR2). We found 259 objects possibly associated with the cluster lying in the vicinity of the giant branch and 1–2 magnitudes fainter/brighter than the main-sequence turn-off in the cluster colour-magnitude diagram, and which cover an area on the sky of $\sim$4.1 deg^2 centered on the cluster. We traced back the orbit of NGC 6362 in a realistic Milky-Way potential, using the `GravPot16` package, for 3 Gyrs. The orbit shows that the cluster shares similar orbital properties as the inner disk, having peri-/apo-galactic distances, and maximum vertical excursion from the Galactic plane inside the corotation radius (CR), moving inwards from CR radius to visit the inner regions of the Milky Way. The dynamical history of the cluster reveals that it has crossed the Galactic disk several times in its lifetime and has recently undergone a gravitational shock, $\sim$ 15.9 Myr ago, suggesting that less than 0.1% of its mass has been lost during the current disk-shocking event. Based on the cluster's orbit and position in the Galaxy, we conclude that the possible extended star debris candidates are a combined effect of the shocks from the Galactic disk and evaporation from the cluster. Lastly, the evolution of the vertical component of the angular momentum shows that the cluster is strongly affected dynamically by the Galactic bar potential. This work has been done in collaboration with Richa Kundu, Jose G. Fernndez-Trincado, Dante Minniti, Edmundo Moreno, Cline Reyl et, al.

Unveiling Vela - variability of interstellar lines in the direction of the Vela supernova remnant - III. Na D and Ca II K

High-resolution optical spectra were obtained in 2017-2019 with the Southern African Large Telescope of fifteen stars in the direction of the Vela supernova remnant. Interstellar Ca II H and K and Na I D lines are discussed. In particular, the line profiles are compared with profiles at a comparable spectral resolution obtained in 1993-1996 by Cha and Sembach. Ten of the lines of sight show changes to one or more of the components in that line of sight. Changes include small changes (1-2 km s^{-1}) in radial velocity and/or increases/decreases in equivalent width over the two decades between the periods of observation. Changes are more obvious in the Ca K line than in the Na D lines. These changes are attributed to gas disturbed by interactions between the supernova ejecta and the surrounding interstellar medium. A representative timescale may be 20-50 years. Small-scale variations in line profiles across the face of the remnant suggest, as previously remarked that a linear scale for interactions is a small fraction of the 40 pc size of the present remnant.

K. Surendra Nadh Somala

Effect of induced seismicity on advanced gravitational wave interferometers

Advanced LIGO and the next generation of ground-based detectors aim to capture many more binary coalescences through improving sensitivity and duty cycle. Earthquakes have always been a limiting factor at low frequency where neither the pendulum suspension nor the active controls provide sufficient isolation to the test mass mirrors. Several control strategies have been proposed to reduce the impact of teleseismic events by switching to a robust configuration with less aggressive feedback. The continental United States has witnessed a huge increase in the number of induced earthquake events primarily associated with hydraulic fracking-related waste water re-injection. Effects from these differ from teleseismic earthquakes primarily because of their depth which is in turn linked to their triggering mechanism. In this work, we discuss the impact caused due to these low magnitude regional earthquakes and explore ways to minimize the impact of induced seismicity on the detector. This work has been done in collaboration with K. Nikhil Mukund, Brian OReilly, and Sanjit Mitra.

Karthik Sriram

Constraining the coronal heights and readjustment velocities based on the detection of a few hundred seconds delays in the Z source GX 17+2

Neutron star Z-type sources provide a unique platform in order to understand the structure of accretion disk-corona geometry emitting close to the Eddington luminosity. Using RXTE and Nuclear Spectroscopic Telescope Array mission (NuSTAR) satellite data, we performed cross correlation function (CCF) studies in GX 17+2 in order to constrain the size of the corona responsible for hard X-rays. From the RXTE data, we found that during horizontal and normal branches, the CCFs showed anti-correlated hard (16-30 keV) and soft (2-5 keV) X-ray delays of the order of a few tens to hundred seconds with a mean correlation coefficient of 0.42 ± 0.11. A few observations show correlated lags and on one occasion, coincident with radio emission. We also report an anti-correlated hard X-ray delay of 113 ± 51 s using the NuSTAR data of GX 17+2. Based on RXTE data, we find that soft and hard X-ray fluxes are varying, indicating the changes in the disk-corona structure during delays. We bridle the size of the corona using relativistic precession, transition layer models, and boundary layer models. Assuming the delays to be a readjustment time scale of the disk-corona structure, the height of the corona was estimated to be 17-100 km. Assuming that the inner region of the truncated disk is occupied by the corona, we constrain the coronal readjustment velocities ($v_{\rm corona} = \beta v_{\rm disk}$, where $v_{\rm disk}$ is the radial velocity component of the disk) of the order of $\beta = 0.06 - 0.12$. This study indicates that the observed delays are primarily dependent on the varying coronal readjustment velocities. This has been studied in collaboration with Siddhart Malu, and Changhwan S. Choi.

L. Sriramkumar

Viable scalar spectral tilt and tensor-to-scalar ratio in near-matter bounces

In a recent work, we constructed a model consisting of two fields—a canonical scalar field and a non-canonical ghost field—that sourced a symmetric matter bounce scenario. The model involved only one parameter, viz. the scale associated with the bounce. For a suitable value of the parameter, the model led to strictly scale-invariant power spectra with a COBE normalized scalar amplitude and a rather small tensor-to-scalar ratio. In this work, we extend the model to achieve near-matter bounces, which contain a second parameter apart from the bounce scale. As the new model does not seem to permit analytical evaluation of the scalar modes near the bounce, with the aid of techniques that we used in our earlier work, we compute the scalar and the tensor power spectra numerically. For appropriate values of the additional parameter, we find that the model produces red spectra with a scalar spectral tilt and a small tensor-to-scalar ratio, which are consistent with the recent observations of the anisotropies in the cosmic microwave background by Planck. This work is done in collaboration with Rathul Nath Raveendran.

Can non-minimal coupling restore the consistency condition in bouncing universes?

An important property of the three-point functions generated in the early universe is the so-called consistency condition. According to the condition, in the squeezed limit wherein the wave number of one

of the three modes (constituting the triangular configuration of wave vectors) is much smaller than the other two, with which the three-point functions can be completely expressed in terms of the two-point functions. It is found that while the consistency condition is mostly satisfied by the primordial perturbations generated in the inflationary scenario, it is often violated in the bouncing models. The validity of the consistency condition in the context of inflation can be attributed to the fact that the amplitude of the scalar and tensor perturbations freezes on super-Hubble scales. Whereas, in the bouncing scenarios, the amplitude of the scalar and tensor perturbations often grows rapidly as one approaches the bounce, leading to a violation of the condition. In this work, with the help of a specific example involving the tensor perturbations, we explicitly show that suitable non-minimal couplings can restore the consistency condition even in the bouncing models. We briefly discuss the implications of the result. This work is done in collaboration with Debottam Nandi.

Parijat Thakur

2016 outburst of H 1743–322: XMM-Newton and NuSTAR View

We report the detection of a type C quasi-periodic oscillation (QPO) along with the upper harmonic in the commensurate ratio of 1:2 in the two observations of the low-mass black hole transient H 1743–322, jointly observed by XMM-Newton and NuSTAR during the 2016 outburst. We find that the QPO and the upper harmonic exhibit shifts in their centroid frequencies in the second observation with respect to the first one. The hardness intensity diagram implies that in contrast to the 2008 and 2014 failed outbursts, the 2016 outburst was a successful one. We also detect the presence of a broad iron Kα line at $\sim$6.5 keV and reflection hump in the energy range of 15–30 keV in both of the observations. Along with the shape of the power density spectra, the nature of the characteristic frequencies and the fractional rms amplitude of the timing features imply that the source stayed in the low/hard state during these observations. Moreover, the photon index and the other spectral parameters also indicate the low/hard state behaviour of the source. Unlike the soft lag detected in this source during the 2008 and 2014 failed outbursts, we observe hard time lags of 0.40 ± 0.15 s and 0.32 ± 0.07 s in the 0.07–0.4 Hz frequency range in the two observations during the 2016 outburst. The correlation between the photon index and the centroid frequency of the QPO is consistent with the previous results. Furthermore, the high value of the Comptonized fraction and the weak thermal component indicate that the QPO is being modulated by the Comptonization process. This work has been done in collaboration with Swadesh Chand, Vivek Kumar Agrawal, Gulab C. Dewangan, and Prakash Tripathi.

Probing transit timing variation and its possible origin with twelve new transits of TrES-3b

We have investigated the possibility of existence of additional planet, as well as the orbital decay and apsidal precession in the extra-solar planetary system TrES-3 through the transit timing variation (TTV) analysis. We have made total twelve transit observations of this system, which include six transits from the 2m Himalayan Chandra Telescope (HCT), IAO, Hanle, India, five from the 1.3m Devasthal Telescope, ARIES, Nainital, India, and one transit from the 1.25m AZT-11 telescope at the Crimean Astrophysical Observatory (CrAO), Crimea. In order to have refine destimation of transit ephemeris, as well as precise TTV analysis, apart from our twelve new transit observations, seventy one more transit data of this system are also considered from the literature. All these eighty three transit light curves are analyzed with uniform procedure through Transit Analysis Package (TAP). By fitting a linear ephemeris model to the eighty three mid-transit times derived from light curve analysis, we have derived new linear ephemeris for orbital period and mid-transit time with $\chi^2_{red} = 1.859$, which indicates that there is an evidence of TTV in TrES-3 system. However, we do not find any indication of periodic-TTV as the significance of the highest peak found in the generated Lomb-Scargle periodogram, which is computed using the timing residuals of linear ephemeris model fit is found to be very far below from the threshold value (FAP = 5%). This allows us to conclude that there is no evidence of additional planet in the TrES-3 system. Since TrES-3b is one of the known hot-Jupiter extra-solar planets, it has been theoretically predicted that the possible TTV may be due to the orbital decay and apsidal precession induced by tidal interactions of TrES-3b and its parent star. These two phenomena have been examined in the TrES-3 system by fitting the or-

bital decay and apsidal precession ephemeris models to transit time data. The orbital decay study shows decreasing period of TrES-3b with the decay rate equals to $4.112 \pm 3.104\ msyr^{-1}$. By assuming this decay rate is real, the estimated remaining lifetime of TrES-3b and the modified tidal quality factor (Q'_*) of the parent star (TrES-3) are found to be $\sim 4.9Myr$ and $\sim 1.11 \times 10^5$, respectively. From the apsidal precession study, the precession rate of the orbit of TrES-3 system is found to be $0.000472 \pm 0.000320\, radepoch^{-1}$. Corresponding to this precession rate, the estimated planetary tidal Love number (kp) of 1.15 ± 0.32 is found to be larger than that of Jupiter. For the selection of optimal model that shows the best fit to the timing data, we have used the Bayesian Information Criterion ($BIC = \chi^2 + klogN$, where N is the total number of data points and k is the number of free parameters) statistic. Because of the smaller value of BIC obtained in the linear model as compared to the orbital decay and apsidal precession models, we have preferred the linear model as best possible model to represent our considered transit time data. This work has been done in collaboration with Vineet Kumar Mannaday, Ing-Guey Jiang, Devendra Kuamr Sahu, and Yogesh C. Joshi.

Sunil Kumar Tripathy

Phantom cosmology in an extended theory of gravity

Some phantom cosmological models without big rip singularity have been constructed in a simple extended theory of gravity. In the geometrical part of the action, a minimally coupled linear function of the Ricci scalar and the trace of the energy momentum tensor have been considered in place of the Ricci scalar. Four Little Rip and Pseudo Rip models have been investigated, where the equation of state parameter evolves asymptotically and sufficiently rapidly to -1. The effect of the coupling constant of the extended gravity theory on the dynamics has been discussed. Possible wormhole solutions for the phantom models are obtained. The possibility of Big trip in wormholes are discussed for the models. This work is done in collaboration with Bivudutta Mishra.

Bouncing cosmology in an extended gravity theory

We have investigated some bouncing models in the framework of an extended gravity theory, where the usual Ricci scalar in the gravitational action is replaced by the sum of the Ricci scalar and a term proportional to the trace of the energy momentum tensor. The dynamical parameters of the models are derived in a most general manner. We considered two bouncing scenarios described by an exponential and a power law scale factors. The non-singular bouncing models also favour a late time cosmic speed up phenomenon. The dynamical behaviour of the equation of state parameter is studied for the models. It is observed that near the bounce, the dynamics is substantially affected by the coupling parameter of the modified gravity theory and is least affected by the parameter of the bouncing scale factors. This work is done in collaboration with Rakesh Kumar Khuntia, and Priyabrata Parida.

Vinutha Tummala

Modified holographic Ricci dark energy model in a scalar tensor Theory of gravitation

In this work, we have studied homogeneous and anisotropic Bianchi type-V metric filled with dark mater (DM) and modified holographic Ricci dark energy (MHRDE) in the framework of scalar-tensor theory of gravitation proposed by Saez and Ballester. To find a deterministic solution for Saez-Ballester field equations, we have used the hybrid expansion law (HEL) for the average scale factor a(t), which yields a time dependent deceleration parameter and exhibits a transition of the Universe from early decelerated phase to the recent accelerating phase. We also have taken the scalar expansion to be proportional to the shear scalar. We have investigated the physical and geometrical properties of the model. It is observed that our model is in good agreement with the ΛCDM model at late times. This work is done in collaboration with V.Uma Maheswara Rao, and Molla Mengesha Nigus

Bianchi type cosmological models in f(R, T) theory with quadratic functional form

The spatially homogeneous and anisotropic Bianchi type III, V and VI_0 cosmological models have been investigated in gravity by choosing the function of the form $R+\alpha R^2+\lambda T$. Here, R is the Ricci scalar, T is the trace of the energy momentum tensor and α, λ are constants. Exact solutions to the field equations of three models are obtained with the

help of hybrid scale factor and the proportionality of shear scalar with expansion scalar (i.e., $\sigma \propto \theta$). We have calculated some physical and geometrical properties of the models and their behaviour is thoroughly studied with the help of their plots with respect to redshift (z). It is observed that for all three models, pressure (p) is negative and energy density (ρ) is positive. In case of Bianchi type V, VI_0 models, the EoS parameter exhibits quintom-like behaviour. Also, by using the same functional form, we have studied all energy conditions for three models. At present ($z = 0$), the energy conditions particularly NEC and DEC are fulfilled, and SEC is violated for all three models, which supports the accelerating expansion of the universe. The advantage of choosing this functional form is that it gives the asymptotically exact de Sitter solution, and also the obtained values of physical parameters matches with the current observational data. This work is done in collaboration with K. Sri Kavya.

Sudhaker Upadhyay

Phase transition of a charged AdS black hole with a global monopole through geometrical thermodynamics

In order to study the phase transition through thermodynamic geometry, we consider the charged AdS black hole with global monopole. We first introduce thermodynamics of charged AdS black hole with global monopole by discussing the dependence of Hawking temperature, specific heat and Pv curve on horizon radius and monopole parameter. By implementing various thermodynamic geometry methods, for instance, Weinhold, Ruppiner, Quevedo and HPEM formulations, we derive corresponding scalar curvatures for charged AdS black hole with a global monopole. Here, we observe that, in contrast to Weinhold and Ruppeiner methods, HPEM and Quevedo formulations provide more information about the phase transition of the charged AdS black hole with a global monopole. This work is done in collaboration with Saheb Soroushfar.

Accretion disks around a static black hole in f(R) gravity

We provide a description of a thin accretion disk for a static spherically symmetric black holes in f(R) gravity. In this regard, we first study the horizons of black holes in f(R) gravity. The equation of motion and effective potential are also computed, which eventually leads to possible existence of innermost circular orbits of accretion disk. We derive the specific energy, specific angular momentum and angular velocity of the particles moving in circular orbits. A comparative study of various parameters is also presented. The locations of the event horizon, cosmological horizon, innermost and outermost stable circular orbits are also pointed out. This work is done in collaboration with Saheb Soroushfar.

Murli Manohar Verma

Extended galactic rotational velocity profiles in $f(R)$ gravity background

An attempt has been made to explore the geometric effects of $f(R)$ action on the galactic dynamics under the weak field approximation. The rotational velocity is calculated beyond the Einstein's geometric theory of gravity. It is inspired by the cosmological geometric relation obtained in the power-law $f(R)$ gravity model in vacuum. We analyse the action with a small positive deviation from the Einstein-Hilbert gravity action (taking R as $f(R) \propto R^{1+\delta}$) at the galactic scales for the explanation of flatness paradox associated with the clustered galactic dark matter. We obtain the contribution of dynamical $f(R)$ cosmological background geometry in accelerating the test mass. Furthermore, the integrated effective acceleration of the test mass due to a massive spherically symmetric source in $f(R)$ background is calculated via the study of geodesics for the suitable spacetime metric, and an equation for the effective rotational velocity has been developed. We test the viability of the proposed model by tracing the motion of test mass far from the disk of galactic matter for smaller δ. The possible galactic rotational velocity curves in $f(R)$ background are discussed for the formula obtained with $\delta << 1$. We also obtain constraints on δ $O(10^{-6})$ confirmed by observations. This work is doen in collaboration with Vipin Kumar Sharma, and Bal Krishna Yadav.

Dark matter as scalaron in $f(R)$ gravity models

We explore the scalar field obtained under the conformal transformation of the spacetime metric $g_{\mu\nu}$ from the Jordan frame to the Einstein frame in

$f(R)$ gravity. This scalar field is the result of the modification in the gravitational part of the Einstein's general relativistic theory of gravity. For $f(R) = \frac{R^{1+\delta}}{R_c^{\delta}}$, we find the effective potential of the scalar field and calculate the mass of the scalar field particle "scalaron". It is shown that the mass of the scalaron depends upon the energy density of standard matter in the background (in solar system, $m_\phi \sim 10^{-16}$ eV). The interaction between standard matter and scalaron is weak in the high curvature regime. This linkage between the mass of the scalaron and the background leads to the physical effects of dark matter, and is expected to reflect the anisotropic propagation of scalaron in moving baryonic matter fields as in merging clusters (Bullet cluster, the Abell 520 system, MACS, etc.). Such scenario also satisfies the local gravity constraints of $f(R)$ gravity. We further calculate the equation of state of the scalar field in the action-angle variable formalism, and show its distinct features as the dark matter and dark energy with respect to energy density of the scalar field at different values of the model parameter δ. This work is done in collaboration with Bal Krishna Yadav.

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Farook Rahaman, and **Saibal Ray**

- *Classical and Quantum Approaches to Black Holes*, Other Editors: I. Radinschi, T. Grammenos, and I.-C. Yang, AHEP, Hindawi (2019).

- *Dark Matter and Dark Energy in General Relativity and Modified Theories of Gravity*, Other Editors: I. Radinschi, C. A. Vasconcellos, and T. Grammenos, AHEP, Hindawi (2019).

- *Theory and Mathematical Aspects of Black Holes*, Other Editors: I. Radinschi, and T. Grammenos, AXIOMS (2020).

(e) BOOK REVIEW

- **G. Ambika,** and **K. P. Harikrishnan**

- *Methods of Non-Linear Time Series Analysis and Applications: Dynamics and Control of Energy Systems,* Editors: A. Mukhopadhyay, S. Sen, D. N. Basu, and S. Mondal, p 9, Springer, doi:10.1007/978-981-15-0536-2_2 (2020).

(f) SUPERVISION OF PhD THESES

Himadri Sekhar Das

- Title: *Study of Physical Properties of Cosmic Dust from Light Scattering.*
  Student: Prithish Halder

Ujjal Debnath

- Title: *Consequences of Various Types of Dark Energy Models in Accelerating Universe and Study of Black Holes.*
  Student: Pameli Saha

- Title: *Study of Inflationary Universe and Cosmological Phenomena of Dark Energy Models.*
  Student: Jyotirmay Das Mandal

Anirudh Pradhan

- Title: *Study of Some Dark Energy Models with Accelerated Expansion of the Universe.*
  Student: Priyanka Garg

Farook Rahaman

- Title: *Relativistic Models of Compact Stars and Wormholes.*
  Student: Tuhuna Manna

- Title: *Features of Galactic Dark Matter and Observational Constraints.*
  Student: Sk Nasarul Islam

Saibal Ray

- Title: *Gravastars in General Relativity.*
  Student: Shounak Ghosh

- Title: *Studies on Strange Stars in General Relativity and Alternative Gravity.*
  Student: Debabrata Deb

- Title: *Homotopy Theorem in Astrophysical System.*
  Student: Abdul Aziz

(g) AWARDS AND DISTINCTIONS

Arunima Banerjee

- Award of a project titled: *Shape and Orientation of the Dark Matter Halo of the Milky Way in the Era of Gaia,* by the Department of Science and Technology, Government of India.

Aru Beri

- Appointed as a Junior Member of the International Astronomical Union, June 2019.

- Awarded Royal Society Newton International Alumni Fellowship, August 2019.

- Appointed as a Young Member in the country team representing India in the International Conference on Women in Physics, to be held at Melbourne, July 2021.

- Included as a Female Scientist of Athena Science Working Group on the International Day of Women and Girls in Science, February 2020.

- Awarded funding from ISRO to hire a JRF for Utilization of AstroSat Archival Data.

Ritabrata Biswas

- First prize in oral presentation (Mathematics), Fourth Regional Science and Technology Congress (Western Region) The University of Burdwan and Department of Science, Technology and Biotechnology, Government of West Bengal, for the paper titled: *Lower Limit of Shear Viscosity to Entropy Density Ratio: String Theoretic Predictions Versus Dark Energy Accretion Results*, 2019.

- Outstanding paper award in oral presentation (Mathematics), Twenty Seventh State Science and Technology Congress, The Department of Science, Technology and

Biotechnology, Government of West Bengal, for the paper titled: *Lower Limit of Shear Viscosity to Entropy Density Ratio: String Theoretic Predictions Versus Dark Energy Accretion Results*, 2020.

Ramesh Chandra

- Elected as a Member of National Academy of Sciences, India.

- **Surajit Chattopadhyay**

- Elected as a Fellow of the Royal Astronomical Society, London, 2020.

- Elected as a Senior Member of International Union of Radio Science (URSI), Belgium, 2019.

Abhirup Datta

- Principal Investigator of the SPARC proposal titled: *Pilot Survey of CMB Polarized Foregrounds using a Single Dish,* 2019 –2021.

- Co-Principal Investigator of the SPARC proposal titled: *Imaging the First Billion Years of the Universe with Next-Generation Telescopes,* 2019 –2021.

- Principal Investigator of the CSIR-EMR project titled: *21 cm Cosmology with the Square Kilometre Array,* 2019.

- Co-Principal Investigator of the CSIR-EMR project titled: *Imaging Diffuse Emission and Possible SZ Signatures in Galaxy Cluster Mergers at High Frequencies,* 2019.

- Co-Principal Investigator of the ISRO –SEAMS project titled: *Astrophysics Space Mission.*

Jibitesh Dutta

- Award of a project titled: *Challenging General Relativity at the Largest Scales: A Systematic Investigation of Cosmological Perturbations in Modified Gravity,* by the Science and Engineering Research Board, Department of Science and Technology, Government of India.

Gaurav Goswami

- Co-Principal Investigator of the project titled: *Cosmological Dark Matter, Primordial Black Holes, Bose-Einstein Condensates, and Charge Asymmetry of the Universe,* under the Indo - Russian Joint Proposal, by the Department of Science and Technology, Government of India.

Shivappa B. Gudennavar

- warded a major research project titled: *Spectro-timing Studies on X-ray Binaries with*

AstroSat, by the Centre for Research Projects, Christ (Deemed to be) University), Bengaluru.

- Awarded a major research project titled: *Investigations on Spectral and Timing Properties of Low Mass X-ray Binaries using AstroSat,* by the Indian Space Research Organization, Bengaluru.

Biswajit Pandey

- Awarded a research project code: *CRG/2019/001110,* by the Science and Engineering Research Board, Department of Science and Technology, Government of India.

Surajit Paul

- NCRA Press Release: Pune Astronomers Lead the Discovery of a New, Rare Type of Radio Sources using the GMRT [http://www.ncra.tifr.res.in/ncra/outreach/press-releases/press-note-for-eisers.pdf].

- IUCAA Press Release: Indian Scientists Discover Vital Clues to Identify the Source of the Highest Energy Cosmic Rays – Particles Coming to Earth from the Universe [https://www.iucaa.in/news/CR/].

Anirudh Pradhan, and B. Sarkar

- Patent for the invention: *A Cylindrical Water Phantom for Machine and Patient Specific Dose,* Official Journal of the Patent Office, Issue No. 38/2019, Dated September 20, 2019, 43207.

Farook Rahaman

- Elected as a Fellow of Royal Astronomical Society, London, 2019.

- Principal Investigator of the project titled: *Theoretical Study on Dark Matter, Gravastar and Wormhole Spacetimes,* by the Science and Engineering Research Board, Department of Science and Technology, Government of India.

- Principal Investigator of the project titled: *Investigation of the Physical Properties and Characteristics of Some Astrophysical Objects,* by JU –RUSA 2.0.

Shantanu Rastogi

- Elected as the Vice-President of the Astronomical Society of India.

Parijat Thakur

- Awarded a project titled: *Exploring the Environment of the Black Hole with the X-ray Binaries using the Archival Data of AstroSat,* by the Indian Space Research Organization.

IUCAA CENTRES FOR ASTRONOMY RESEARCH AND DEVELOPMENT (ICARDs)

Department of Physics, Cooch Behar Panchanan Barma University (CBPBU), Cooch Behar

(Coordinator: Ranjan Sharma)

Areas of Research

- Theoretical Astrophysics, and Cosmology.
- The department has two faculty members, and ten research scholars, working in the field of theoretical astrophysics and cosmology. The department offers specialization in General Relativity, Astrophysics and Cosmology at the post-graduation level.

Colloquia/ Seminars

- A colloquium at the Department of Physics, CBPBU, by Simome Giacche, and Alessia Palmese (Institute of Theoretical Physics, University of Giessen, Germany), on April 29, 2019.
- A seminar at the Department of Physics, CBPBU, by Sujay Paul (Department of Atmospheric Sciences, University of Calcutta, Kolkata), on September 19, 2019.
- CBPBU hosted Rituparno Goswami (School of Mathematics, Statistics and Computer Science, University of KwaZulu-Natal (Westville Campus), Durban, South Africa) during January 8 – 11, 2020. He delivered lectures, and interacted with the faculty members, research scholars, and students of the university.

Publications using ICARD Facilities

- S. Thirukkanesh, Ranjan Sharma, and Sunil D. Maharaj (2019) Anisotropic generalization of Vaidya-Tikekarsuperdense stars, EPJP, 134,378.
- Kalikkuddy Komathiraj, Ranjan Sharma, Shyam Das, and Sunil D. Maharaj (2019) Generalized Durgapal-Fuloria relativistic stellar models, JApA,40,37.
- Ranjan Sharma, Shyam Das, Megan Govender, and Dishant M. Pandya (2020) Revisiting Vaidya and Tikekar stellar model in the linear regime, AnPhy, 414,168079.

Outreach Programmes

- Ranjan Sharma delivered a public lecture when he visited the University of KwaZulu-Natal, South Africa, during June 2 – 23, 2019 for collaborative research work.

Department of Physics and Astrophysics, University of Delhi

(Coordinator: T. R. Seshadri)

Areas of Research

- Astronomy, Astrophysics, and Cosmology.

Lecture Series

- On Gravitational Radiation, by Mohd. Sirtaz (University of Delhi): (i) Emission of electromagnetic radiation and gravitational radiation due to dyon-dyon interaction, (ii) Interaction of gravitational waves with test masses, and (iii) Transverse traceless gauge and spin of the graviton.
- On Plasma Physics, by Sunil Malik (University of Delhi).

Seminars

- X-ray Astronomy, by Panini Shrikant (IIA, Bengaluru).
- Quantum Process in Electromagnetic and Gravitational Background: A Comparison, by Manjeet Kaur (University of Delhi).

Observational Proposals

- Magnetic field profile in galaxy clusters by rotation measure of background QSOs.
- Probing magnetic field structure in galaxy clusters using RM and depolarization.

Workshop

- School on Introductory General Relativity and Cosmology: This school was conducted at the Central University of Tamil Nadu, Thiruvarur, during January 4 – 11, 2020. T. R. Seshadri, L. Sriramkumar, H.S. Mani, and Dawood Kothawala were the resource persons, and they were assisted by Sampurnanand Jha, and Ramkishor Sharma. Since it had been noticed that the Astronomy and Astrophysics (A & A) activities in Universities of Tamil Nadu were very limited as compared to those in the rest of the country, it was felt that such a workshop with special emphasis on teaching A & A in this region could correct this anomaly.

Publications using ICARD Facilities

- MGaveshna Gupta, Ramkishor Sharma, and T. R. Seshadri (2020) Scalar spectral index in the presence of primordial black holes, IJMPD, 29, 2050029.
- Sunil Malik, Hum Chand, and T. R. Seshadri (2020) Role of intervening Mg II absorbers on the rotation measure and fractional polarization of the background quasars, ApJ, 890, 132.
- Ramkishor Sharma, Kandaswamy Subramanian,and T.R. Seshadri (2020) Gravitational wave generation in a viable scenario of inflationary magnetogenesis, PhRvD, 101, 103526.
- Richa Kundu, Jose G. Fernandez-Trincado, Dante Minniti, Harinder P. Singh, Edmundo Moreno, et al. (2019) The tale of the Milky Way Globular Cluster NGC 6362 -- I. The orbit and its possible extended star debris features as revealed by Gaia DR2, MNRAS, 489, 4565.
- N. Kameswara Rao, David L. Lambert, Arumalla B. S. Reddy, Ranjan Gupta, ..., and Harinder P. Singh (2020) Unveiling Vela – variability of interstellar lines in the direction of the Vela supernova remnant – III. Na D and Ca II K, MNRAS, 493, 497.

Department of Physics, DDU Gorakhpur University

(Coordinator: Shantanu Rastogi)

Areas of Research

- Circumstellar and Interstellar Medium.
- Molecules of Astrophysical Importance.
- Star Clusters.
- Atmospheric Aerosols.
- Trace Gases in Planetary Atmospheres.

Amit Pathak (Banaras Hindu University, Varanasi), and Shantanu Rastogi (DDU Gorakhpur University) have been studying various aspects of astrophysical mid-infrared emission features, and the possible carrier polycyclic aromatic hydrocarbon (PAH) molecules. Theoretical studies on chemical pathways to formation of pre-biotic molecules in interstellar medium are being done by Alka Mishra (Lucknow University). Numerical codes developed to compute the energy dependent time-lag, and r.m.s. from a thermal Comptonized medium have been performed by Sanjay Pandey (LBS (PG) College, Gonda). Continuous monitoring of atmospheric aerosols at Gorakhpur is being carried out by Shantanu Rastogi.

Workshop

- Workshop on Exploring the Universe:The resource persons were: Durgesh Tripathi, Kanak Saha, Shantanu Rastogi, and Sanjay Pandey (i) At the Department of Physics, DDU Gorakhpur University, on November 21, 2019, and (ii) At the LBS (PG) College, Gonda, on November 22, 2019.

Publications using ICARD Facilities

- Manisha Yadav, Shivani, Alka Misra, and Poonam Tandon (2019) Theoretical study of possible reaction mechanisms for the formation of carbodiimide in the interstellar medium and polarizabilities of carbodiimide, OLEB, 49, 89.
- Samuzal Barua, Vadakkumthani Jithesh, Ranjeev Misra, Gulab C. Dewangan, Rathin Sarma, and Amit Pathak (2020) NuSTAR observation of Ark 564 reveals the variation of coronal temperature with flux, MNRAS, 492, 3041.
- Mridusmita Buragohain, Amit Pathak, Itsuki Sakon, and Takashi Onaka (2020) DFT study on interstellar PAH molecules with aliphatic side groups, ApJ, 892,11.
- Prayagraj Singh, Aditya Vaishya, Shantanu Rastogi, and S. Suresh Babu (2020) Seasonal heterogeneity in aerosol optical properties over the subtropical humid region of northern India JASTP, 201, 105246.
- Aftab Ahmad, Shivani, Alka Misra, and Poonam Tandon (2020) Theoretical approach to study the formation of C2H4O2 isomers in interstellar medium through reaction between interstellar formaldehyde molecules, RAA, 20, 14.
- Sanjay K. Pandey, and Ranjeev Misra (2020) Software to compute the energy dependent time-lag and r.m.s. from a thermal comptonized medium, AstroSat Advanced Resources [http://astrosat-ssc.iucaa.in/?q=data_and_analysis].

Public Lectures

- First ever real photograph of a black hole, by Shantanu Rastogi, DDUGU, April 12, 2019.
- Dynamics of the Sun's atmosphere, by Durgesh Tripathi (IUCAA), BHU, Varanasi, April 18, 2019
- Moon: 50 years since first visit by man, by Shantanu Rastogi, DDUGU, July 20, 2019.

Department of Physics, Gurukula Kangri University, Haridwar

(Coordinator: Hemwati Nandan)

Areas of Research

- Classical Gravity, and Cosmology.

Research

- Study of the shadows cast as well as deflection of light around a dual charged stringy black hole.
- Study of gravitational lensing around a rotating BTZ black hole in (2+1) dimensional gravity.
- Investigating the geometry of a rotating black hole surrounded by quintessence in diverse contexts.
- Various gravitational aspects such as energy extraction (via the Penrose process and Superradiance), particle collisions around a N=2, U(1)2 dyonic rotating black hole in the gauged supergravity model.
- Collision of two massive particles with non-zero intrinsic spin moving in the equatorial plane in the background of a Schwarzschild black hole surrounded by quintessential matter field.

Workshop

- Mini-Workshop for Educators in Astronomy and Skywatch was organised on November 27, 2019,at the Department of Physics, Gurukula Kangri University, Haridwar, in collaboration with Aryabhata Research Institute of Observational Sciences (ARIES), Nainital.



Publications using ICARD Facilities

- Arindam Kumar Chatterjee, Kai Flathmann, Hemwati Nandan, and Anik Rudra (2019) Analytic solutions of the geodesic equation for Reissner-Nordstrom–(anti–) de Sitter black holes surrounded by different kinds of regular and exotic matter fields, PhRvD, 100, 24044.

- Amar Deep, Chhavi P. Pandey, Hemwati Nandan, K. D. Purohit, Narendra Singh, et al. (2019) Evaluation of ambient air quality in Dehradun city during 2011–2014, JESS, 128, 96.
- Nanda Kishore, Atul K. Srivastava, Hemwati Nandan, Chhavi P. Pandey, S. Agrawal, et al. (2019) Long-term (2005–2012) measurements of near-surface air pollutants at an urban location in the Indo-Gangetic Basin, JESS, 128, 55.
- Amare Abebe, Mudhahir Al Ajmi, Maye, Elmardi, Hemwati Nandan, and Noor ul Sabah (2020) Shear-free conditions of a Chaplygin-gas-dominated universe [arXiv: 2003.09441v1].
- Anik Rudra, Hemwati Nandan, Radouane Gannouji, Soham Chakraborty, and Arindam Kumar Chatterjee (2020) Energy extraction and particle acceleration around a rotating dyonic black hole in N = 2, U(1)2 gauged supergravity [arXiv: 1906.03566v5].
- Prateek Sharma, Hemwati Nandan, Radouane Gannouji, Rashmi Uniyal, and Amare Abebe (2020) Deflection of light by a rotating black hole surrounded by quintessence, IJMPA, 35, 2050155.

Outreach Programmes

- Skywatch on November 27, 2019.

Honours/Distinctions/Awards

- Hemwati Nandan has been offered Honorary Position of Extra-ordinary Associate Professor at the Center for Space Research (CSR), North-West University, South Africa, for the period January 1, 2020 - December 31, 2022.
- Shobhit Giri has been presented Young Scientist Award, for the best presentation of the work on Motion of spinning test particle around Schwarzschild black hole (SBH) surrounded by quintessence, during the 14th Uttarakhand State Science and Technology Congress, held at Dehradun during February 27 - 29, 2020.

Department of Physics, BITS - Pilani, Hyderabad

(Coordinator: Rahul Nigam)

Areas of Research

- Measurement of Hubble Constant.
- Application of Machine Learning and Deep Learning.
- Effect of Primordial Magnetic Field on Early Structure Formation.
- Studies of Dense Matter in Neutron Star.

Research

- We have tried to measure the Hubble constant based on various distance ladder based methods through the already available unique data obtained from Hubble Space Telescope (HST). Our analysis is based on parametric (T-test) as well as non-parametric statistical methods such as the Mann-Whitney U test and Kolmogorov Smirnov test.
- We have been investigating the applications of novel algorithms using Machine Learning and Deep Learning in Astronomy. We developed and implemented Generative Adversarial Network to generate CMB data and then compared it with different data available from various experiments like WMAP and Planck. Further, we are trying to extract CMB using a Multi-layer Perceptron (MLP) classifier trained on the CAMB models. We further correlate the baryon density obtained from the power spectrum of simulated CMB temperature maps with the corresponding map image and form the data set for training the neural network model.

Workshops/Schools

- Physics and Observations of Stars, Virtual Observatory and its Tools, by Priya Hasan.
- Gaia: The 3D Milky Way Mapper, by Najam Hasan.
- Telescope Making, by Tushar and Atharva.

Publications by using ICARD Facilities

- Smruti Smita Lenka, Prasanta Char, and Sarmistha Banik (2019) Properties of massive rotating proto neutron stars with hyperons: Evolution and universality, JPhG, 46, 10.
- Somnath Mukhopadhyaya, and Sarmistha Banik (2020) Gravitational waves from r-mode instability of massive young sub- and super-Chandrasekhar white dwarfs, EPJP, 135, 270.
- Krishna Prakash Nunna, Sarmistha Banik, and Debarati Chatterjee (2020) Signatures of strangeness in neutron star merger, ApJ, 896, 109.
- Rahul Nigam (2020) Corrections to halo model due to primordial magnetic field in a universe with non-zero cosmological constant, Ap&SS, 365, 25.
- Amit Mishra, Pranath Reddy, and Rahul Nigam (2020) Baryon density extraction and isotropy analysis of Cosmic Microwave Background using Deep Learning [arXiv: 1903.12253].

Outreach Programmes

We organized many sky observation sessions for the institute students as well as campus community. A popular level talk was delivered by Rahul Nigam in BITS – Pilani, Hyderabad; and Osmania University, Hyderabad, on Black Hole Physics.

Department of Physics, Cochin University of Science and Technology (CUSAT), Kochi

(Coordinator: Titus K. Mathew, and Co-coordinator: Charles Jose)

Areas of Research

- Gravitation, Cosmology, andAstrophysics.

Research

- We have shown that the first law of thermodynamics, dE=TdS+WdV cannot be formulated properly for a non-flat universe using proper invariant volume. We have also investigated the status of the first law of the form □dE=TdS in a non-flat universe, and then shown that the energy change, dE within the horizon and the outward energy flux are not equivalent to each other in a non-flat universe when we use the proper invariant volume.
- Holographic Ricci dark energy evolving through its interaction with dark matter is a natural choice for the running vacuum energy model. We have analyzed the relative significance of two versions of this model in the light of SNIa, CMB, BAO, and Hubble data sets using the method Bayesian inferences.
- We have been also working on understanding the large scale structure of the universe using numerical simulations and analytic models. In particular, we have been trying to use new statistical tools for characterizing the largescale distribution of galaxies.

Workshop

- Workshop on Emergent Gravity Paradigm: This workshop was conducted at CUSAT during November 8 – 10, 2019.The focus was on different aspects of emergent gravity phenomena. The key resource person was T. Padmanabhan (IUCAA), and the others were: Dawood Kothawala (IIT – Madras, Chennai), Kinjalk Lochan (IISER, Mohali), Sumanta Chakraborty (IACS, Kolkata), Karthik Rajeev (IUCAA), and Titus K. Mathew.

Publications using ICARD Facilities

- Thuruthipilly Hareesh, P.B. Krishna, and Titus K. Mathew(2019) First law of thermodynamics and emergence of cosmic space in a non-flat universe, JCAP, 12, 24.
- N. D. Jerin Mohan, P.B. Krishna, Athira Sasidharan, and Titus K. Mathew (2020) Dynamical system analysis and thermal evolution of the causal dissipative model, CQGra, 37, 75007.
- P. B. Krishna, and Titus K. Mathew (2020) Emergence of cosmic space and the maximization of horizon entropy[arXiv: 2002.02121].
- Paxy George, and Titus K. Mathew (2020) Bayesian analysis of running holographic Ricci dark energy, MNRAS[arXiv: 1906.08532].

Outreach Programmes

- Seminar on Astronomy Scope and Opportunities for the Students, at St. Paul's International School, Kalamassery, June 22, 2019.
- Workshop on Scientific Awareness, and 50 Years of Apollo Mission: This was conducted in association with IUCKLAM and KSSP for the general public, at CUSAT, July 12, 2019.
- Public Lecture on History and Physics of Space Mission, at Aquinas College, Edakochi, August 1, 2019.

- Regional Training Programme on Annular Solar Eclipse, at ICARD, Department of Physics, CUSAT, November 16, 2019.
- Regional Training Programme on Annual Solar Eclipse, at the Government College, Madappally, Kozhikode, November 23, 2019.
- Regional Training Programme on Annual Solar Eclipse, at the Government College, Kariavattom, November 23, 2019.
- Annular Solar Eclipse Observation and Regional Training Programme, at ICARD, Department of Physics, CUSAT, December 26, 2019.







Department of Statistics, University of Calcutta, Kolkata

(Coordinator: Asis Kumar Chattopadhyay)

Areas of Research

- Big Data Analysis Related to Astronomical Objects, Star Formation, Distance Determination, and Measure of Chaos.
- Large Scale Simulation.
- Development of Computer Programmes and Statistical Techniques for Analysis of Astronomical Data.

Research

- Exploring the origin of the formation of star clusters in our Galaxy and in Small Magellanic Cloud (SMC) through simulated HR diagrams and compare with observed star clusters. The simulation study produces synthetic H-R diagrams by Markov Chain Monte Carlo (MCMC) technique using 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.
- Subjective classification of spiral galaxies is not suitable for studying the effect of bars on their physical characteristics. In reality, it is to comprehend the complex correlations in a multivariate parametric space. An objective classification of a large data set (26,089) of spiral galaxies were prepared as a value added galaxy catalogue from SDSS DR 15 virtual data archive. Independent Component Analysis is used to determine the observed features (namely ionised lines, Lick indices, photometric and morphological properties). Subsequently, a K-means cluster analysis is applied to the 14 best chosen Independent Components to obtain 12 distinct homogeneous groups.

Workshop/Seminar

- Workshop on Statistical Applications in Astronomy and Astrophysics: This workshop was conducted at the Department of Statistics, Assam University, Silchar, during November 20 – 22, 2019. The resource persons were: Sanjeev V. Dhurandhar, Aditya Chattopadhyay, Gaurangadeb Chattopadhyay, Tanuka Chattopadhyay, Atri Deshamukhya, Himadri Sekhar Das, Rama Shanker, and Dibyojyoti Bhattacahrjee.
- National Seminar on Applications of Statistics in Natural Sciences: This seminar was organised at the Departments of Statistics and Physics, St. Xavier's College, Kolkata, during December 16 - 17,2019. Poster presentations showcasing the research of college and university teachers and research scholars from different fields of natural sciences were arranged. There were specialized sessions by Ayanendranath Basu, Saurabh Ghosh, Supratik Pal, and Rajesh Kumble Nayak.

Publications using ICARD Facilities

- Abhishek Senapati, Tridip Sardar, Krishnendra Sankar Ganguly, Krishna Sankar Ganguly, Asis Kumar Chattopadhyay, et al. (2019) Impact of adult mosquito control on dengue prevalence in a multi-patch setting: A case study in Kolkata (2014 – 15), J. Th. Bio., 478, 139.
- Suman Paul, and Tanuka Chattopadhyay (2020) Random fragmentation of turbulent molecular cloud lying in the central region of giant galaxies,NewA, 80, 101423.
- Sukanta Das, Tanuka Chattopadhyay, and Sailajananda Mukherjee (2020) Three dimensional episodic model of star formation in galaxies in the presence of dissipation, MNRAS, 494, 4098.
- Soumita Modal, Tanuka Chattopadhyay, and Asis Kumar Chattopadhyay (2020)Unsupervised classification of eclipsing binary light curves through k-medoids clustering, J. App. Stat.,47, 376.

Outreach Programmes

- Regular sky watch programmes were arranged by Tanuka Chattopadhyay at the University of Calcutta.

Department of Physics, University of Calicut, Kozhikode

(Coordinator: C.D. Ravikumar)

Area of Research

- Morphological Analysis of Galaxies, and High Energy Studies of Active Galaxies.

Research

- Sruthi, Baheeja, and Vinod have been studying the connection between the central intensity ratio and various other photometric and spectroscopic parameters in order to understand the co-evolution scenario of galaxies. Sitha, Amina and Habib Rahman study broadband spectra of blazars in an attempt to unravel the mysteries associated with production of extremely energetic emission from the central region of galaxies.

Seminars

- Astronomy Congress - 2019: The ICARD initiated its activities in the Department of Physics by joining hands with Kerala Sastra Sahitya Parishad to conduct the Astronomy Congress-2019, during April 27-28, 2019, in connection with the celebrations of 50th anniversary of first Moon Landing. The fully residential programme hosted about 150 participants, including over 100 students from schools in the districts of Kozhikode and Malappuram. There were experiments to find due north, to understand precession of the Earth, observation of Sun, and to mimic eclipses. There were demonstrations and presentations by K. Pappootty, P. T. Ramachandran, Jiji Varghese, V. V. Manikandan, C. Subramanian, P. Sajin, Ilyas Perumbilam, Ananthamurthy, P. Sudhir, A. Sreedharan, and C. D. Ravikumar. In addition, a night sky watch was also conducted.
- National Seminar on Observations and Research in Astronomy and Astrophysics: This seminar was intended for motivated post-graduate students of Physics from colleges, affiliated to University of Calicut, and was held during November 27-29, 2019. The resource persons were: K. Indulekha, Ajit Kembhavi, Anand Narayanan, Sachin Pachat, Ninan Sajeeth Philip, G. Rajasekharan, A. N. Ramaprakash, C. S. Stalin, and M. Vivek. In addition, there was a detailed telescope making and night sky watch session.

Outreach Programmes

- Workshop on Tools and Techniques for Watching and Recording the Sky: The workshop, held during December 20–21, 2019, was intended for students from nearby colleges, and public to get training to make small telescopes, and observe the sky. Training was given on small ready-made telescopes. There was a session on astrophotography also.
- Solar Eclipse Watch: This was done in collaboration with Kerala Sastra Sahitya Parishad on December 26, 2019. Live observation of solar eclipse was conductedfrom five locations near the administrative block of the University of Calicut using projection methods. Over 500 people participated in it.

Publication using ICARD Facilities

- S. Aswathy, and C.D. Ravikumar (2020) Co-evolution of nuclear rings, bars and thecentral intensity ratio of their host galaxies, RAA, 20,15.

School of Physical Sciences, Swami Ramanand Theerth Marathwada University (SRTMU), Nanded

(Coordinator: Madhav K. Patil)

Areas of Research

- **AGN Feedback in Galaxy Clusters:** AGN residing in the deep potentials of the galaxy groups or clusters play an important role in shaping morphology of the hot gas halos surrounding them, and result in the formation of cavities or bubbles in the surface brightness distribution of the galaxy clusters. These cavities are formed due to the displacement of the relativistic plasma by the radio jets originating from the central AGN. Researchers from SRTMU are involved in investigating and quantifying the power injected by the radio jets into the ICM by measuring pdV work of the cavities, and checks their balance with that quantified by studying radio jets. This study involves analysis of high resolution X-ray data from Chandra X-ray Telescope and multi-frequency radio data acquired using uGMRT. Collaborators in this study are Somak Raychaudhary (IUCAA), Dharam Vir Lal (GMRT), Ishwar Chandra (NCRA), and Sachindra Naik (PRL).

- **Soft X-ray Excess Emission from Type 1 AGNs:** It is observed that a significant fraction of type 1 AGNs exhibit soft X-ray excess emission below ~2 keV. Though several attempts have been made over last two decades, origin of this soft X-ray excess has remained a major problem in the AGN research. Systematic study of this component using the most advanced observing facilities like, Chandra and XMM-Newton, has shown that the soft excess emission is a smooth continuum component rather than a blend of emission/absorption features.

- **Correlation between X-ray vs. Optical/UV Variability of AGNs:** Variability is the most striking property of AGNs, whose observed brightness as well as spectral shapes are found to vary on various timescales from minutes to years scale. Current AGN physics predict that the optical emission mostly comes from the accretion disk, whereas the X-ray emission originates from the Compton up-scattering of disk photons in the corona, which is present surrounding the central super massive black hole (SMBH). So it is obvious that there must be a coupling between the disk and corona emission. Researchers from SRTMU with Ranjeev Misra and Gulab Chand Dewangan (both from IUCAA), using the simultaneous observing capabilities at Optical/UV and X - ray wavelengths of the space-born telescopes like AstroSat, XMM-Newton, and Swift are involved in investigating the inter-band variability properties of AGN.

- **X-ray Binary Sources (XRBs):** The researchers from SRTMU are involved in the study of XRB population in star forming galaxies. This study is based on the X-ray data acquired using the LAXPC onboard of AstroSat, and is carried out in collaboration with Ranjeev Misra and Gulab Chand Dewangan.

- **Dust Extinction and Multiphase ISM in Early-type Galaxies:** The researchers from SRTMU are also involved in the study of multiphase ISM in early-type galaxies in collaboration with S. K. Pandey (SRTMU) and Ajit Kembhavi (IUCAA). This study is based on multi-frequency observations of early-type galaxies selected from different environments.

Workshop/Lecture Series

- **International Workshop on LIGO-India (IWLI-2019):** This workshop was organized during December 15 - 16, 2019 in association with IUCAA, and Indian Space Research Organization (ISRO), Bengaluru. As the proposed site of the LIGO-India falls within the jurisdiction of SRTMU (~ 60 km North), and therefore, SRTMU naturally attracts more attention and is expected to play a lead role in generating interest among the young talents from the nearby region. This workshop was intended mainly for young research scholars, post-doctoral fellows and young faculty members from universities, science and engineering colleges. Coordinators for this workshop were Ajit Kembhavi and Sukanta Bose (both from IUCAA), and Madhav K. Patil (SRTMU).



- **Lecture Series on General Theory of Relativity and Gravitational Wave Detection:** A series of lectures were given by Sanjeev Dhurandhar (IUCAA), during January 15 -16, 2020. There were more than 200 participants, consisting of MSc, MPhil, and PhD students, and faculty member. He covered Newtonian Mechanics, Theory of Relativity, Spacetime Geometry, Curved Spacetime, GW Formation and their Detection. He also shed light on building of the LIGO-India and its advantages for the researchers from this region.

Visitors

- A team of four senior scientists: Michael Landry, Joseph Giaime, Dennis Coyne, and Richard Savage (all from LIGO Observatories, USA), along with Sanjit Mitra and Suresh Doravari (both from IUCAA) visited the School on April 15, 2019, and had detailed discussions on the proposed activities at SRTMU, and its involvement in the LIGO – India project with Udhav Bhosle (Vice Chancellor, SRTMU).
- Anil Kakodkar visited the School of Physical Sciences, on June 18, 2019, wherein he interacted with the faculty as well as MSc, MPhil and PhD students of the School.
- Gadre (IIT – Bombay, Mumbai) visited the School on July 20, 2019, and interacted with the faculty and students.

Outreach Programmes

- Public lecture by Jayant Narlikar on Gurutviya Tarang – Gravitational Waves, was organised on December 15, 2019, and was intended for school, college students and the science loving general public at large from Nanded city with a central theme to educate them on importance of the gravitational waves, and implications of the up-coming LIGO – India project in the vicinity of this university. The public lecture was attended by more than 5,000 and was the unique event in the history of the University.
- Public lecture by Fredrick Raab on Challenges in Building GW Detectors was also arranged at MGM's College of Engineering, Nanded.
- ICARD-SRTMU has been conducting wide range of science popularization activities as a part of the science outreach of the University and the LIGO-EPO. Public lectures, demonstrations, sky-watch,

discussions, lab visits, etc. are the regular features of the ICARD. The School of Physical Sciences of SRTMU has recently developed an astronomical observatory, equipped with fully automated 16″ ACF Schmidt Cassegrain Smart Mount Computer Controlled MEADE Optical Telescope with SBIG ST-10XME CCD camera, SBIG Self Guiding Spectrometer and SSP-3, SPP-3A backend detectors. The telescope is housed in a 3.5 m fully steerable motor driven fibre dome procured from Sirius Observatories, Australia. These facilities are being regularly used for conducting the science popularization activities. More than 50 schools and colleges, and hundreds of students from this region have visited this facility, where faculty and research scholars of the School gave presentations, demonstrations, and slide shows. Faculty of the ICARD-SRTMU regularly visit schools, colleges in this region and deliver popular/public lectures, conduct workshops, hands-on activities, and seminars.

- Madhav K. Patil has delivered the following public/popular lectures: (i) On Gravitational Waves: A Tool to Explore Unexplored Universe, on October 15, 2019, at Lal Bahaddur Shastri College, Dharmabad, (ii) On World of Stars, on September 1, 2019, at Shivaji Science College, Kalburgi, (iii) On Opportunities in Astronomy after Graduation and Post-Graduation, on September 30, 2019, at Maharashtra Mahavidyalaya, Nilanga, and (iv) On Excitements in Astronomy, for the students of Toshniwal Mahavidyalaya, Hingoli, as a part of their educational tour to School of Physical Sciences, SRTMU.
- Slide show followed by visit to the observatory for BSc Final Year students of Gramin Mahavidyalaya, Vasannagar, Mukhed.
- Demonstrations followed by observatory visit for the students from Indira School, Nanded, on October 5, 2019.
- Educational tour of more than 100 students from Yogeshwari Mahavidyalaya, Ambejogai, to the observatory and astrophysics lab.
- Public lecture on Wonders in the Sky followed by sky-watch using 16″ telescope on the occasion of the National Science Day Celebration.

School of Studies in Physics and Astrophysics, Pt. Ravishankar Shukla University, Raipur

(Coordinator: Nand Kumar Chakradhari)

Areas of Research

- Supernovae, X-ray Binaries, Galaxies, and Variable Stars.

Research

- Study of type Ia supernovae has been carried out using optical photometric and spectroscopic data obtained from 2m Himalayan Chandra Telescope. UV-optical photometric data of these events were also archived from Swift-UVOT. This is an ongoing collaborative work of Nand Kumar Chakradhari, Shritika Tiwari (ICARD, Raipur),G. C. Anupama, and Devendra Kumar Sahu (IIA, Bengaluru). Further, study of chemically peculiar stars has been carried out in collaboration with Santosh Joshi (ARIES, Nainital).

- Spectral and timing analyses of X-ray Binaries, e.g., GRS 1915+105, GX339-4 have been carried out using AstroSat and RXTE data by Kalyani Bagri, and S. K. Pandey (ICARD, Raipur), in collaboration with Jagdish S. Yadav (TIFR, Mumbai), and Ranjeev Mishra (IUCAA).

- Study of central region of lenticular galaxies is being carried out by Mahendra Verma, and S.K. Pandey (ICARD, Raipur), and Sudhanshu Barwey (IIA, Bengaluru).

Publications using ICARD Facilities

- Nand Kumar Chakradhari, Devendra Kumar Sahu, and G. C. Anupama (2019) Optical and UV studies of type Ia supernovae SN 2009ig and SN 2012cg, MNRAS, 487, 1886.

- Mridweeka Singh, Kuntal Misra, Devendra Kumar Sahu, Raya Dastidar, …, Nand Kumar Chakradhari, et al.(2019) Observational properties of a type Ib supernova MASTER OT J120451.50+265946.6 in NGC 4080, MNRAS, 485, 5438.

- Daniel Nhlapo, Santosh Joshi, Bruno Letarte, Nand Kumar Chakradhari, and Sanjeev Kumar Tiwari (2019) Ground-based photometric survey to search for the pulsational variability in Bp, Ap, and Am stars, BSRSL, 88, 248.

Outreach Programmes

- **Invited/Public Lectures**

(I) India in space, at the Regional Science Centre, Raipur, on September 25, 2019, (ii) Mathematics and astronomy, at the School of Studies in Mathematics, Pt. Ravishankar Shukla University, Raipur, on September 26, 2019, (iii) Supernova explosions, in the International Seminar, at St. Josephs' College, Darjeeling, during October 21 – 22, 2019, (iv) Dr. Meghnad Saha and his research, in the National Seminar, at SCERT, Raipur, on November 16, 2019, (v) A glimpse of thermonuclear Supernovae, and (vi) Spreading astronomy teaching, both the talks in the 38th Meeting of the Astronomical Society of India, held during February 13 – 17, 2020, at IISER, Tirupati,

- **Sky Watching Programmes at Raipur**

(i) May 25, 2019, (ii) On the occasion of Partial Lunar Eclipse, July 16 – 17, 2019, (iii) INSPIRE Programme, August 6 – 10, 2019, (iv) 46th Jawahar Lal Néhru Childern's Science Congress, SCERT, October 17, 2019, and (v) On the Partial Solar Eclipse December 26 2019.

- **Visit of Students**

(I) Kalinga University, Raipur, visited ICARD, on November 8, 2019, and (ii) Government P. G. College, Kurud, Dhamatari, visited ICARD, on November 21, 2019. On both the occasions, the students interacted with the faculty members, and there were astronomical lectures, planetarium shows, and telescope and lab demonstrations.

- **Television Programmes**

(i) Launch of Chandrayaan – 2, broadcasted live by Zee News MP Chhattisgarh Channel, July 22, 2019, (ii) Vikram Lander, Prgyan Rover and Chandrayaan – 2, broadcasted live by IBC 24 Hour Channel, September 6, 2019, https://youtu.be/FLS0QfVu5fo, (iii) Soft Landing of Vikram Lander – Chandrayaan – 2, broadcasted live by Zee News MP Chhattisgarh Channel, September 7, 2019 morning, (iv) Chandrayaan – 2, broadcasted live by Zee News MP Chhattisgarh Channel, September 7, 2019 evening, and (v) Invited as an expert on Space Missions of ISRO and Chandrayaan – 2, broadcasted live by Doordarshan Chhattisgarh Channel, September 8, 2019, https://youtu.be/vHrVtQG0T8o,

Honours

- Nand Kumar Chakradhari has been selected for INSA Visiting Scientist Fellowship 2020 – 21.









Department of Physics, Tezpur University

(Coordinator: Rupjyoti Gogoi)

Areas of Research

- Astronomical Observations, and Data Analysis.

Workshops/Schools

- North East Meet of Astronomers (NEMA – V): Since 2015, Department of Physics, Tezpur University, in association with IUCAA, initiated a series of meetings to promote interaction and collaborations among Astronomers of North East India. The idea of such meetings is to bring together young researchers including faculty members, research scholars and advance level post-graduate students on a single platform to share their current and future research ideas. NEMA–V was organized by theICARD, during September 11–13, 2019. The resource persons were Durgesh Tripathi, and Kanak Saha from IUCAA, and their valuable feedback and suggestions to the young researchers were much appreciated, making the interaction sessions vibrant.
- Workshop on Astronomical Data Analysis (WADA): The ICARD extended support to the Department of Physics, Jagannath Barooah College, Jorhat, Assam, to organize this workshop during September 17 – 19, 2019. The workshop was intended for graduate and post-graduate students, research scholars and college/university teachers from different parts of India, who have been working in the area of Astronomy and Astrophysics. There were extensive hands-on sessions on AstroSat data analysis, conducted by the research scholars, under the valuable guidance of Ranjeev Misra (IUCAA).
- Workshop on Solar Astronomy and Safe Solar Observation: This workshop was organized on February 22, 2020 at Fakaruddin Ali Ahmed High School, Borghat, Tezpur. School students were grouped into different teams and were taught to make sundial, and solar projector by using the kits supplied by the volunteers from Tezpur University Astronomy Club. Interesting facts about Sun were explained by the volunteers with the help of sundial and solar projector.

Publications using ICARD Facilities

- Sonali Sachdeva, Rupjyoti Gogoi, Kanak Saha, Ajit K. Kembhavi, and Somak Raychaudhury (2019) Formation of disc galaxies around z~2, MNRAS, 487, 1795.
- Rukaiya Khatoon, Zahir Shah, Ranjeev Misra, and Rupjyoti Gogoi (2020) Study of long-term flux and photon index distributions of blazars using RXTE observations, MNRAS, 491, 1934.
- Pranjupriya Goswami, Atreyee Sinha, Sunil Chandra, Ranjeev Misra, ..., Rupjyoti Gogoi, et al. (2020) Unravelling the unusually curved X-ray spectrum of RGB J0710 + 591 using AstroSat observations, MNRAS, 492, 796.





Department of Physics, Newman College, Thodupuzha

(Coordinator: Joe Jacob)

Areas of Research

- Radio Astronomy, X-ray Astronomy, and Machine Learning.

Workshops/Schools

- Workshop on Introduction to Astronomy and Astrophysics: The ICARD), in collaboration with the Astronomical Society of Kerala (ASK) organized thisworkshop at the UC College, Aluva, during August 29 – 30, 2019, for the benefit of post-graduate, and highly motivated under-graduate students from various colleges and universities in Kerala. The objective of the workshop was to foster interest in Astronomy and Astrophysics among the students in the region and to motivate students to take up this stream of science and explore the exciting possibilities in this field. The workshop consisted of lectures, sky watch, and problem solving sessions, and was organized as a tribute to late Professor V. C. Kuriakose (Department of Physics, CUSAT), the mentor for generations of astronomers from Kerala, whose remembrance day was August 30. The resource persons were: K. Babu Joseph, K. Indulekha, Sajeeth Ninan Philip, Joe Jacob, Minu Joy, Arun K. G., Charles Jose, Tharanath R., Nijo Varghese, Saneesh S., and Prasia P. The coordinator was Joe Jacob.

- Workshop for School Science Teachers: This workshop was organised on February 22, 2020, in collaboration with the Breakthrough Science Society (BSS), as part of the National Science Day Celebrations 2020. There were lectures on Building Scientific Temper, by P. N. Thankachen (Secretary, Kerala Chapter, BSS), and on Teaching Science through Simple Experiments Performed using Things Available in the Household, by K. K. Raveendran (BSS, Kottayam). The generation of electricity from circuits made using potatoes and tomatoes, and the demonstration of the concept of center of gravity using simple straws were much useful. The workshop was coordinated by Joe Jacob, and Noble C. Kurian (Department of Physics, Newman College).

Outreach Programme

- Students Seminar Competition on Recent Advancements in Physics: A contest for the students to present the recent advancements in Physics as short seminars was conducted on the February 29, 2020, in the occasion of the National Science Day. The aim was to develop the skill of literature search as well as science presentation skills among students. Prizes were given to the best presentations.

Award

- Joe Jacob was presented the prestigious Professor Sivaprasad Memorial Best Teacher Award in the state of Kerala. He was selected from nearly one hundred applications, and the award consisted of Rs. 25,000/-, and a citation, and was given on June 15, 2019.

BALANCE SHEET

The Bombay Public Trust Act, 1950. Schedule VIII [Vide Rule (1)]

Name of the Trust : INTER-UNIVERSITY CENTRE FOR ASTRONOMY & ASTROPHYSICS

Address: Post Bag-4,Ganeshkhind, Pune-7. **Registration No. :F-5366 (PUNE) dated 27.1.1989.**

BALANCE SHEET AS AT 31ST MARCH 2020

Sr No.	FUNDS & LIABILITIES	Schedule No.	31.03.2020 Rs.
1	Trust Fund / Corpus	6	**1,99,59,969**
2	Grant-In-Aid from UGC	7	**1,23,77,65,083**
3	Other Earmarked Funds and Project Grants	8	**38,72,33,301**
4	Projects and Other Payable	9	**13,38,71,963**
5	Current Liabilities	10 & 10A	**28,46,92,162**
6	Income and Expenditure a/c	14	**(45,70,55,270)**
	Total		**1,60,64,67,209**

Sr No.	ASSETS & PROPERTIES	Schedule No.	31.03.2020 Rs.
1	Fixed Assets	11	**78,39,55,437**
2	Investments / Deposits	12	**72,71,07,034**
3	Project & Other Receivables	13	**1,75,18,248**
4	Current Assets -	13	
	a) Cash, Bank balances & Revenue Stamps		**2,06,18,754**
	b) Loans and Advances	13A	**3,38,35,856**
	c) Deposits		**29,57,616**
	d) Prepaid Expenses		**1,32,24,866**
	e) Advance to Suppliers	13B	**72,49,397**
	Total		**1,60,64,67,209**

For Inter-University Centre for Astronomy & Astrophysics

M.S.Sahasrabudhe
Admin. Officer (Accounts)

N. V. Abhyankar
(Sr.Admn.Officer)

Prof. Somak Raychaudhury
(Director / Trustee)

Place : Pune
Date : 27.07.2020

As per Report of even date
For A.H.Joshi & Co.
Chartered Accountants
FRN -112396W

S.A. Joshi
(Partner)
Membership No : 037772

Chairperson
Governing Board



अंतर - विश्वविद्यालय केंद्र : खगोलविज्ञान और खगोलभौतिकी

INTER - UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

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