28th ANNUAL REPORT 2015-16

IUCAA

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

28th ANNUAL REPORT 2015-16

IUCAA

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

EDITOR

ASEEM PARANJAPE

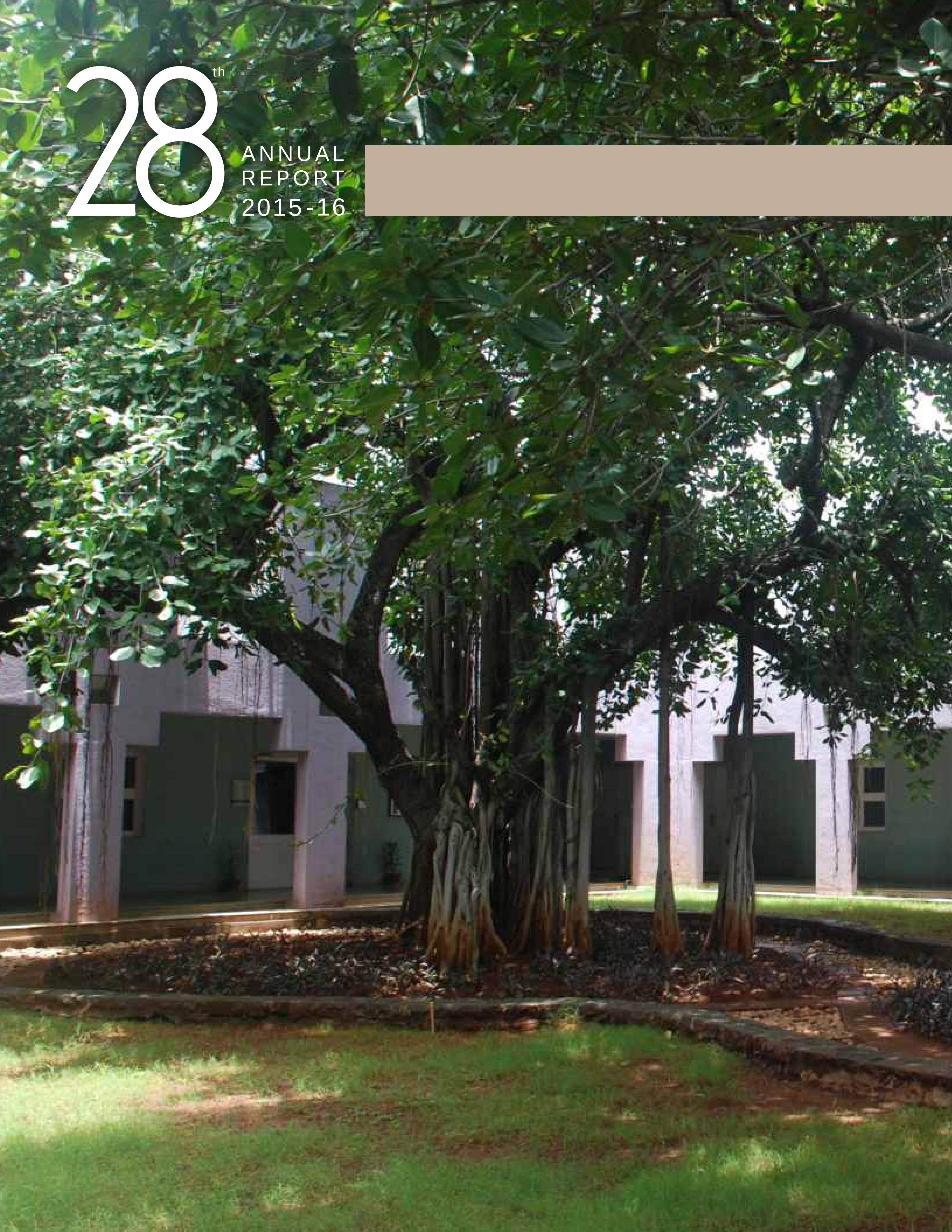
e-mail : aseem@iucaa.in

EDITORIAL ASSISTANT

MANJIRI MAHABAL

e-mail: mam@iucaa.in

28th ANNUAL REPORT 2015-16



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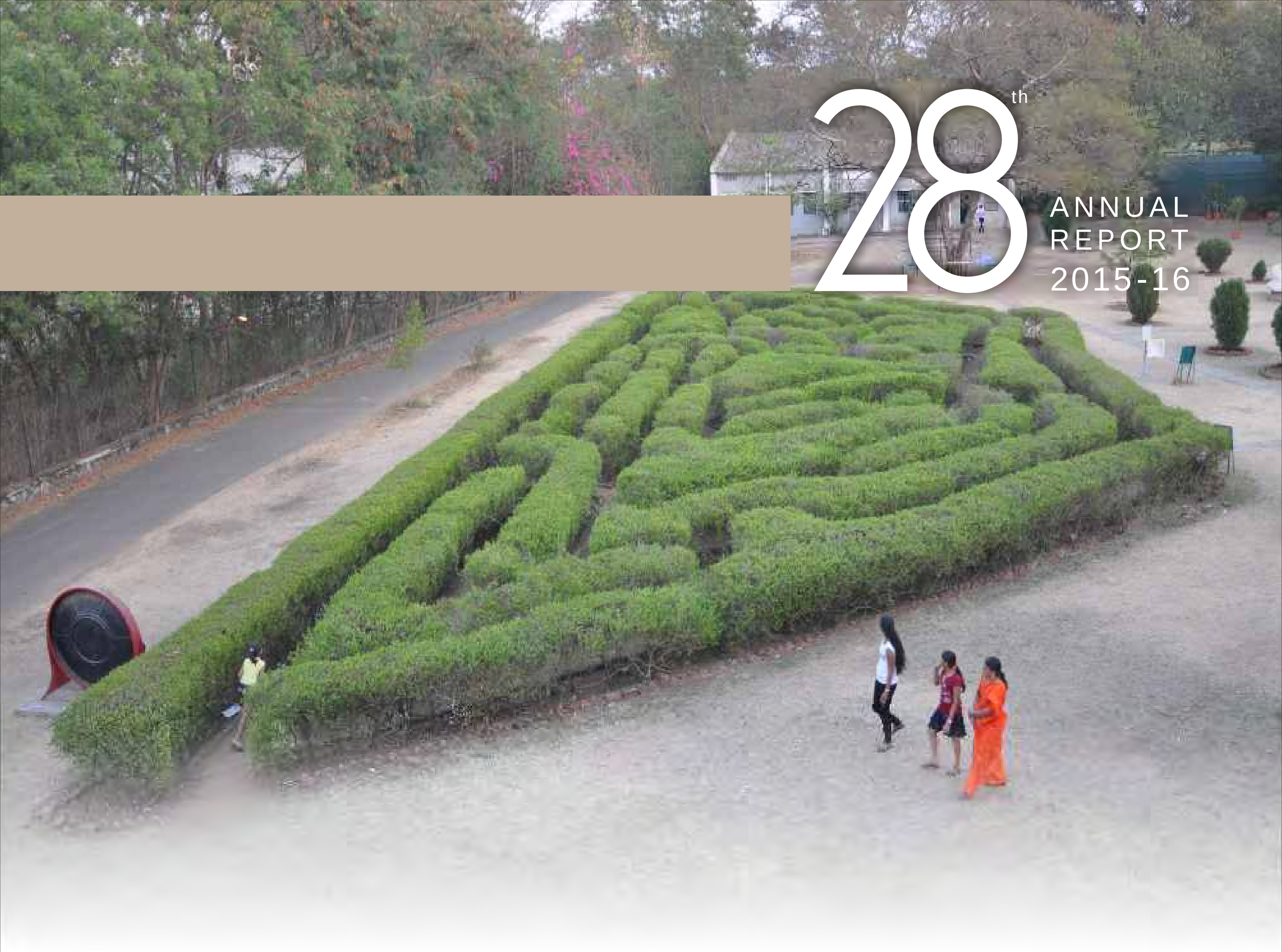

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Satadru Bag
Suman M. Bala
Prasanta Bera
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Sumanta Chakraborty
Kabir Chakravarti
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Russell Cannon,
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National Centre for Radio Astrophysics, Pune.

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7. Narayan Banerjee, Department of Physical Sciences, IISER, Kolkata
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13. Archana Bora, Department of Physical Sciences, Gauhati University, Guwahati
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16. Shuvendu Chakraborty, Department of Mathematics, Seacom Engineering College, Howrah
17. Subenoy Chakraborty, Department of Mathematics, Jadavpur University, Kolkata
18. Ramesh Chandra, Department of Physics, Kumaun University, Nainital
19. Suresh Chandra, Department of Physics, Lovely Professional University, Phagwara, Punjab
20. Ritaban Chatterjee, Department of Physics, Presidency University, Kolkata
21. Suchetana Chatterjee, Department of Physics, Presidency University, Kolkata
22. Asis Kumar Chattopadhyay, Department of Statistics, Calcutta University, Kolkata
23. Surajit Chattopadhyay, Department of Computer Application, Pailan College of Management and Technology, Kolkata
24. Tanuka Chattopadhyay, Department of Applied Mathematics, Calcutta University, Kolkata
25. Raghavendra Chaubey, Faculty of Science, Banaras Hindu University, Varanasi
26. Bhag Chand Chauhan, Department of Physics and Astronomical Sciences, Central Univ. of Himachal Pradesh, Dharamshala
27. Rabin Kumar Chhetri, Department of Physics, Sikkim Government College, Gangtok
28. Himadri Sekhar Das, Department of Physics, Assam University, Silchar
29. Mamta Dahiya, Department of Physics and Electronics, S. G. T. B. Khalsa College, Delhi
30. Sudipta Das, Department of Physics, Visva Bharati University, Santiniketan
31. Dhurjati Prasad Datta, Department of Mathematics, University of North Bengal, Siliguri
32. Ujjal Debnath, Department of Mathematics, Bengal Engineering and Science University, Howrah
33. Atri Deshamukhya, Department of Physics, Assam University, Silchar
34. S. Dev, Department of Physics, H.N. Bahuguna Garhwal Central University, Srinagar, Uttarakhand
35. Jishnu Dey, Department of Physics, Presidency University, Kolkata
36. Mira Dey, Department of Physics, Presidency University, Kolkata
37. Broja Gopal Dutta, Y. S. Palpara College, Purba - Medinipur
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39. Sunandan Gangopadhyay, Department of Physics, West Bengal State University, Barasat, Kolkata
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42. Sarbari Guha, Department of Physics, St. Xavier's College, Kolkata
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110. Anisul Ain Usmani, Department of Physics, Aligarh Muslim University

FROM AUGUST 2015

1. Rizwan Ul Haq Ansari, Department of Physics , Maulana Azad National Urdu University, Hyderabad
2. Ritabrata Biswas, Department of Mathematics, Bankura University
3. Debasish Borah, Department of Physics, Indian Institute of Technology, Guwahati
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VISITING ASSOCIATES

The Twenty-Sixth batch (2015) of Visiting Associates, who were selected for a tenure of three years, beginning August 1, 2015.


RIZWAN UL HAQ ANSARI


RITABRATA BISWAS


DEBASISH BORAH


JIBITESH DUTTA


PRIYA HASAN


CHARLES JOSE


BISWAJIT PANDEY


SANJAY K. PANDEY


DIPANKAR PAUL


ANANTA CHARAN PRADHAN


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SWATI ROUTH


PRASANT SAMANTRAY


SANIL UNNIKRISHNAN

KUNWAR PRATAP SINGH

The appointment of following Visiting Associates of the Twenty-Third batch has been extended for three years : Gazi Ameen Ahmed, Sk. Saiyad Ali, Shyamal Kumar Banerjee, Prasad Basu, Koushik Chakraborty, Mamta Dahiya, Broja Gopal Dutta, Sarbari Guha, Joe Jacob, Deepak Jain, Minu Joy, Soumen Mondal, Hemwati Nandan, Rajesh Kumble Nayak, Bikash Chandra Paul, Amit Pathak, Farook Rahaman, C. D. Ravikumar, Sanjay Kumar Sahay, Sandeep Sahijpal, Asoke Kumar Sen, Somasri Sen, Shanthi K., Ranjan Sharma, Parijat Thakur and Pranjal Trivedi.

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The Director

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Varun Sahni

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Dipankar Bhattacharya

Head, Publications
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Aseem Paranjape

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Ranjeev Misra

Head, Infrastructural Facilities
Tarun Souradeep

Head, Observing Programmes and SALT
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Ranjan Gupta

Head, Grievance Cell
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DIRECTOR'S REPORT

IUCAA has been at the forefront of fundamental research, the development of teaching pedagogy and science outreach in almost all branches of Astrophysics, Cosmology and Theoretical Physics at the national and international levels for almost three decades. It is both a privilege and a challenge for me to be given the responsibility of leading this unique and illustrious institution.

I took over the role of the Director from Professor Ajit Kembhavi, who was one of the founding members of IUCAA, serving in various key positions, notably as the Dean of Visitor Academic Programmes, and then as the third Director. As the Dean of VAP, Professor Kembhavi's tireless efforts in widening the scope of IUCAA's research, particularly in computational and observational astrophysics to researchers at Indian universities, largely helped IUCAA to establish itself as a premier institution of research in the world, as well as succeed in its original mandate to being a central facility for connecting university faculty and students to the international stage of astrophysics research. He is also one of the pioneers in use of the internet in Indian academia, leading the establishment of network access for institutions of higher education in India, and later, facilitating the access to online library and journal to Indian universities. I am also proud to succeed Professor Jayant Narlikar, the founder-Director, who, in addition to being a pioneer cosmologist and inspirational communicator of science, conceived and built IUCAA to aspire to the highest possible standards, and Professor Naresh Dadhich, who enhanced IUCAA's scope of research and collaboration worldwide, as well as its educational and cultural activities.

This has been a year of intense excitement for researchers at IUCAA. The discovery of the first ever signal of a gravitational wave by the LIGO-VIRGO Consortium in September 2015 using the two LIGO observatories in the USA, and a subsequent second detection in December, represented a culmination of decades of efforts by an international collaboration. IUCAA has been an important part of this collaboration from its inception, with Professor Sanjeev Dhurandhar developing the foundations of the data analysis techniques that were used for these discoveries. The group of gravitational wave astronomers that he groomed at IUCAA now lead various aspects of the search for gravitational waves in India and across the world, and many of them were authors of the discovery paper. The Indian consortium of gravitational wave research, IndIGO, which includes 37 authors of the discovery paper, was also formed and consolidated at IUCAA.

This year also saw the launch of India's first space-borne multi-wavelength astronomical observatory satellite, AstroSat, launched by ISRO in September 2015. IUCAA has had scientific and technical contributions to all payloads on this satellite, with the operations centre for CZTI being located, and the proposal processing system being developed at IUCAA. It also provides a unique opportunity to carry out various research programmes of IUCAA members and visiting associates. Some initial exciting results have emerged already. IUCAA members are also building SUIT, a payload for ISRO's Aditya - L1 mission to study the Sun.

Among honours, Professor Ajit Kembhavi has been elected a Vice-President of the International Astronomical Union (IAU), Professor Tarun Souradeep has been elected the President of the Indian Association for General Relativity and Gravitation (IAGRG), and Professor Aseem Paranjape elected an Associate of the Indian Academy of Sciences, Bengaluru. Professor Ajit Kembhavi and Professor Sanjeev Dhurandhar have been offered Emeritus Professorship, while Professor Varun Sahni's services have been extended for two years.

Our academic programmes continue to grow. During 2015 - 16, ten research scholars and seven post-doctoral fellows have joined, while five research scholars have obtained Ph.D. degrees. IUCAA academic members have published 108 papers, while the 126 IUCAA visiting associates have published 201 papers in peer-reviewed journals.

IUCAA is the key stakeholder for science in LIGO - India mega-project. The site selection committee, with Professor Ajit Kembhavi as the Chair and Dr. P.D. Gupta (RRCAT, Indore) as the Co-Chair, has shortlisted two sites, and the final site will be decided soon. The IUCAA Date Centre for the support of the activities of the LIGO scientists (Tier - 2), and elsewhere in India and the world is near completion.

In the Thirty Metre Telescope (TMT) project, the building work on the mountain Mauna Kea is stalled due to a verdict by the Supreme Court of Hawaii, but the fabrication and development works in partner countries continue. IUCAA leads the development of the telescope control system (TCS) software, on which work has already commenced.

IUCAA holds about 6.75% share of the world's largest working telescope, Southern African Large Telescope (SALT), situated in Sutherland, South Africa. This translates into about 20 nights per year excluding calibration time. The performance of the telescope is consistently improving, and the efficiency of the telescope is currently high. Several IUCAA visiting associates from Indian universities are engaged in research with this telescope with the assistance from IUCAA scientists.

There are currently six IUCAA Resource Centres (IRCs), located at Delhi, Kochi, Kolkata, Raipur, Siliguri, and Udaipur, three University Centres at Kozhikode, Nanded, and Tezpur, and four IUCAA Nodes for Astronomy and Astrophysics Development (INAAD) at colleges in Delhi, Gangtok, Pune, and Thodupuzha. Of the twenty eight meetings/workshops/schools organised by IUCAA during the year, twelve were at different colleges/universities across the country. Of these, six were organised by these centres. At present, IUCAA has been on the process of revamping these centres to utilize the facilities more effectively. The very extensive outreach work done by IUCAA members in the local community and through its regional centres continues to thrive.

The world-leading research at IUCAA, and at Indian universities through the network of IUCAA visiting associates, owes a great deal to the hard working and talented core and contractual staff at our institution. I wish to express my sincere gratitude to every one of them, and to our mentors, the Governing Board, with Dr. Srikumar Benerjee as the Chair, the Council, with Dr. Ved Prakash as the Chair. We sincerely acknowledge the help, advice and support from the University Grants Commission, and its officers and staff, in every sphere of our activities.

Somak Raychaudhury
Director

AWARDS AND DISTINCTIONS

Sukanta Bose

Excellence in Professional Service Award, College of Arts and Sciences, Washington State University, USA.

Science Lead, LIGO - India Project.

Neeraj Gupta

CSIRO Australia Chairman's Medal.

Ajit Kembhavi

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

Jayant V. Narlikar

Awarded D.Sc. (Honoris Causa) degree, Presidency University, Kolkata.

Awarded Dr. Narendra Dabholkar Smruti Samajik Puraskar from Satara Nagar Parishad.

Awarded Swargiya Mohan Dharia Rashtranirrman Puraskar from Vanarai Foundation, Nagpur.

Aseem Paranjape

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

Tarun Souradeep

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

RESEARCH FELLOWSHIPS/GRANTS

Arunima Banerjee

INSPIRE Faculty Fellowship, DST, New Delhi.

Varun Bhalerao

INSPIRE Faculty Fellowship, DST, New Delhi.

Dipankar Bhattachraya

AstroSat Science Support Cell Grant, ISRO, Bengaluru.

Sukanta Bose, Ajit Kembhavi, Sanjit Mitra, and Tarun Soueradeep

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

Anuradha Gupta

National Post-doctoral Fellowship, DST, SERB, New Delhi.

Girjesh Gupta

INSPIRE Faculty Fellowship, DST, New Delhi.

Neeraj Gupta

Start-up Research Grant, DST, New Delhi.

Research Grant, Indo-French, CFIPRA.

Indo - South Africa Flagship Programme in Astronomy Grant, NRF, South Africa and DST, New Delhi.

Ajit Kembhavi

NKN - NIC Data Diverse Initiative in Astronomy Grant, New Delhi.

Sanjit Mitra

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

T. Padmanabhan

J.C. Bose Fellowship, DST, New Delhi.

Aseem Paranjape

Ramanujan Fellowship, DST, SERB, New Delhi.

A.N. Ramaprakash

Thirty Metre Telescope (TMT) Grant, DST, New Delhi.

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

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

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

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

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

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

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

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

A.N. Ramaprakash and Durgesh Tripathi

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

Durgesh Tripathi

Max-Planck Partner Group Research Grant, Max-Planck Society, Germany, and DST, New Delhi.

HIGHLIGHTS OF THE YEAR

THE DISCOVERY OF GRAVITATIONAL WAVES

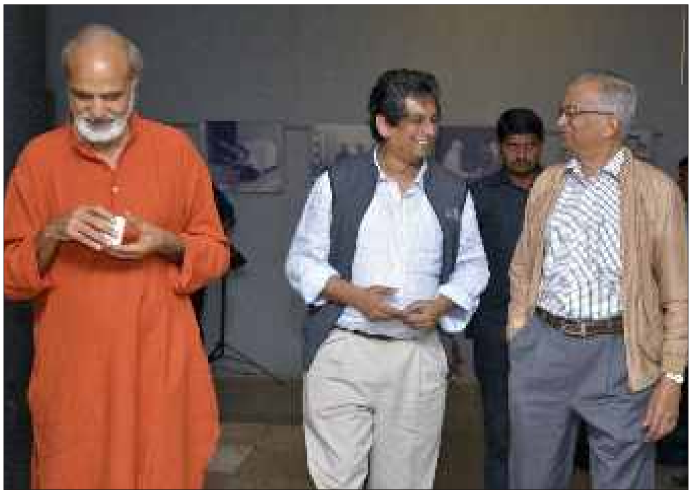
Members of LIGO-India team met the Prime Minister prior to his departure to USA, where the LIGO-India MoU was signed.
(L to R) Tarun Souradeep, Dhiraj Bora, R. Chidambaram, Sekhar Basu, Narendra Modi, R D. Gupta, and Somak Raychaudhury

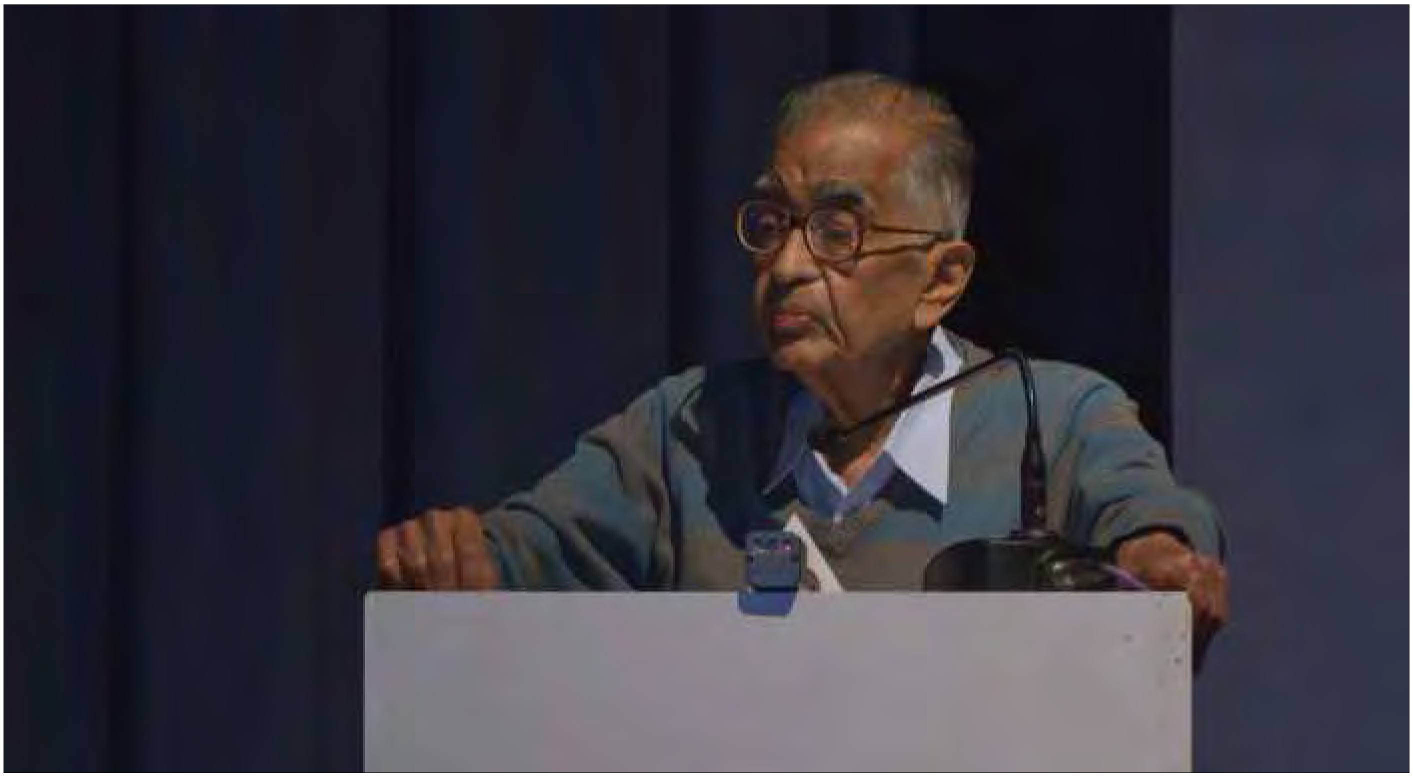
Marking a historic moment in science, gravitational waves were first detected on September 14, 2015 by both of the twin Laser Interferometer Gravitational-wave Observatory (LIGO) detectors, located in Livingston, Louisiana; and Hanford, Washington, USA. The result was announced to the world on February 11, 2016 by the LIGO Science Collaboration (LSC), which involved a significant contribution from scientists in India. IUCAA hosted a synchronised press event on behalf of the nationwide gravitational wave community on the evening of February 11 that carried on to a second session on the morning of February 12, 2016. Top science journalists and media persons from all over the country attended these events. The major science news, together with the Indian contributions got wide coverage in the Indian news media, internet and television, including prime time TV coverage on the evening of February 11. The celebrations at IUCAA was graced by science luminaries, Anil Kakodkar, Jayant Narlikar, and chairperson of the IUCAA Governing Board, Srikumar Banerjee. Highlights of the two day celebration were, the presence of C .V. Vishveshwara, whose early prediction of black hole ring down made in 1971 was borne out in this discovery; a hugely attended public talk on February 12 by Sanjeev Dhurandhar, IUCAA, an Indian pioneer in gravitational wave research; and most importantly, the dramatic revelation by IUCAA director, Somak Raychaudhury of the three well timed tweets from the Prime Minister of India that hailed the global science discovery, the Indian contribution and hinted at Union Cabinet approval for LIGO-India in the near future.

The current Indian gravitational wave scientific community has arisen out of research programmes carried out over three decades. Notably, at IUCAA, the group led by Sanjeev Dhurandhar, who initiated and did foundational work on developing data-analysis techniques to detect these weak signals buried in the detector noise and led the solo Indian group in the LSC in the initial era of LIGO for a decade. Currently, the pan-Indian participation in the LSC, under the umbrella of the *Indian Initiative in Gravitational-wave Observations* (IndIGO), involves sixty-one scientists from nine institutions, namely: CMI Chennai, ICTS-TIFR Bengaluru, IISER-Kolkata, IISER-Thiruvananthapuram, IIT Gandhinagar, IPR Gandhinagar, IUCAA Pune, RRCAT Indore, and TIFR Mumbai. Most members

Signing of the LIGO-India MoU in USA on March 31,2016.

of these GW science teams nation-wide attended the celebrations at IUCAA and had an opportunity to interact with the national media. The events was jointly organised and managed by gravitaional wave researchers at IUCAA with great help from the IUCAA science outreach and the administration.





CELEBRATING THE DISCOVERY OF GRAVITATIONAL WAVES

The discovery of gravitational wave paves the road to the possibility of observing our universe if one can locate their source with an additional detectors placed in India, far from the LIGO detectors, forming one or more large triangles. The global science community is unanimous that the key to the future of gravitational wave science, beyond the discovery phase launched with the announcement on February 11, 2016, lies with the LIGO-India observatory.

The Union Cabinet of India has granted `in principle' approval on February 17, 2016 to the LIGO-India mega science proposal. LIGO-India will establish a state-of-the-art gravitational wave Advanced LIGO detector on the Indian soil in collaboration with LIGO Laboratory, led by Caltech and MIT, USA. This was rapidly followed up by the signing of an MoU between the National Science Foundation, USA and the Department of Atomic Energy and Department of Science and Technology of India on March 31, 2016 in the USA in the presence of the Prime Minister of India. These steps make an emphatic statement of the Indian government's commitment to the rising aspirations of the Indian science to make a far-reaching impact in the global arena of science and technology, and to provide opportunity to the country's youth to proudly look forward to careers in international-level science research within the country.

The observed signal was created by two massive black holes merging together in a galaxy 1.3 billion light years away. The masses of the black holes are 36 and 29 times the mass of the Sun. Black holes are so high in density that these massive black holes are actually even smaller than earth. The two merging black holes and the resulting bigger black holes are shown in approximate scale in the above image.

The LIGO-India project will be jointly coordinated and executed by three premier Indian lead institutions: The Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune of the University Grants Commission, with DAE organisations, the Institute for Plasma Research (IPR), Gandhinagar; and the Raja Ramanna Centre for Advanced Technology (RRCAT), Indore. LIGO-India will be jointly funded by the Department of Atomic Energy (DAE) and the Department of Science and Technology (DST). IUCAA, the key science stakeholder of LIGO-India will be responsible for the science teams, human resources development, data acquisition and scientific data computation. Under an MoU, IUCAA would continue to extend logistic support to the IndIGO consortium of researchers in this field spread over a dozen premier institutions, namely, the IITs at Gandhinagar, Madras (Chennai), and Kanpur; IISERs at Thiruvananthapuram, Kolkata and Pune; Chennai Mathematical Institute; ICTS Center of TIFR, Bengaluru; and the University of Delhi.

Besides the grand promise of launching a new field of gravitational wave astronomy, LIGO-India will be a premier and frontier science experiment. It will involve laser, optics, vacuum and control system technologies at cutting edge of global capabilities and bring together the best in fundamental science and high end technology available in Indian national research laboratories, IITs, IISERs and Universities. IUCAA welcomes wide participation in this frontier science endeavour from universities and institutions nationwide.

GRAVITATIONAL WAVES TEAM OF IUCAA

CONGRATULATIONS !!!

DETECTION OF GRAVITATIONAL WAVES AWARDED THE MILNER'S SPECIAL BREAKTHROUGH PRIZE IN FUNDAMENTAL PHYSICS

For the detection of Gravitational Waves (Published in Physical Review Letters, **116**, 061102, February 11, 2016), opening new horizons in Astronomy and Physics, the special Breakthrough Prize in Fundamental Physics has been awarded. The Breakthrough Prizes in Fundamental Physics are funded by the Milner Global Foundation. The US $ 3 million award will be shared between two groups of laureates: The three founders of the Laser Interferometer Gravitational-Waves Observatory (LIGO), will each equally share US $ 1 million, and 1,012 contributors to the experiment will each equally share US $ 2 million.

The 3 founders of the LIGO are: Ronald W.P. Drever (Caltech), Kip S. Thorne (Caltech), and Rainer Weiss (MIT) USA. Among the 1,012 contributors, 8 are present members of IUCAA, 6 are former members, and among these are 2 visiting associates of IUCAA. Also, there are 2, who were long term project student/post-doctoral fellow in IUCAA. They are:

Present Members

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

Former Members

Arunava Mukherjee
Archana Pai
Jayanti Prasad
B.S. Sathyaprakash

Former Members and Visiting Associates

Rajesh K. Nayak
Anand S. Sengupta

Former Project Student/ Post-Doctoral Fellow

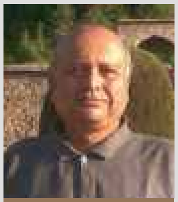
Swetha Bhagwat
Soma Mukherjee

The laureates will be recognized at a ceremony in the Fall of 2016, where the annual Breakthrough Prizes in Fundamental Physics (including the special prize) will be presented. The Prime Minister of India, Shri Narendra Modi has congratulated the Indian contributors through Social Media.

The entire team has also been awarded the Gruber Cosmology Prize for 2016. The monetary award of US $ 0.5 million will go to the three founders, but the entire team of contributors has been recognised in the award.

ANIRBAN AIN

SUKANATA BOSE



SANJEEV DHURANDHAR

SHARAD GAONKAR

ANURADHA GUPTA

SANJIT MITRA

NIKHIL MUKUND

TARUN SOURADEEP

ARUNAVA MUKHERJEE

ARCHANA PAI

JAYANTI PRASAD

B.S. SATHYAPRAKASH

RAJESH K. NAYAK

ANAND S. SENGUPTA

SWETHA BHAGWAT

SOMA MUKHERJEE

Shri Anil Shirole, Member of Parliament, Pune visited IUCAA on February 21, 2016 to felicitate the scientists engaged in gravitational wave research. He also has extended his full support to IUCAA in its endavour to set up LIGO-India.

IUCAA ACADEMIC CALENDAR

IUCAA Events

2015

April 20 - May 1
Training Programme in Astronomy for African Scientists

April 20 - May 20
School Students' Summer Programme and Astronomy Camp

April 29 - May 1
Workshop on Gravitational Waves / Boot Camp

May 4 - June 5
Refresher Course in Astronomy and Astrophysics
(for college and University Students)
Cooridinator: Aseem Paranjape

May 4 - June 19
Vacation Student's Programme
Cooridinator: R. Srianand

September 21 - 26
Cloudy Workshop
Coordinator: Gulab Dewangan

October 26 - 29
IRIS (Interface Region Imaging Spectrometer) Data Analysis Workshop
Coordinators: Durgesh Tripathi and Girijesh Gupta

November 05 - 10
Mini Workshop on AstroSat CZTI

November 23 - 28
Indo-French Astronomy School for Optical Spectroscopy
Coordinators: Ranjan Gupta, Philippe Prugniel and Mamta Pommier

December 15 - 24
IUCAA-NCRA Radio Astronomy Winter School
Coordinators: Neeraj Gupta (IUCAA) and Subhashis Roy (NCRA)

2016

January 18
UK - India Educational Research Initiative Meeting on AstroSat

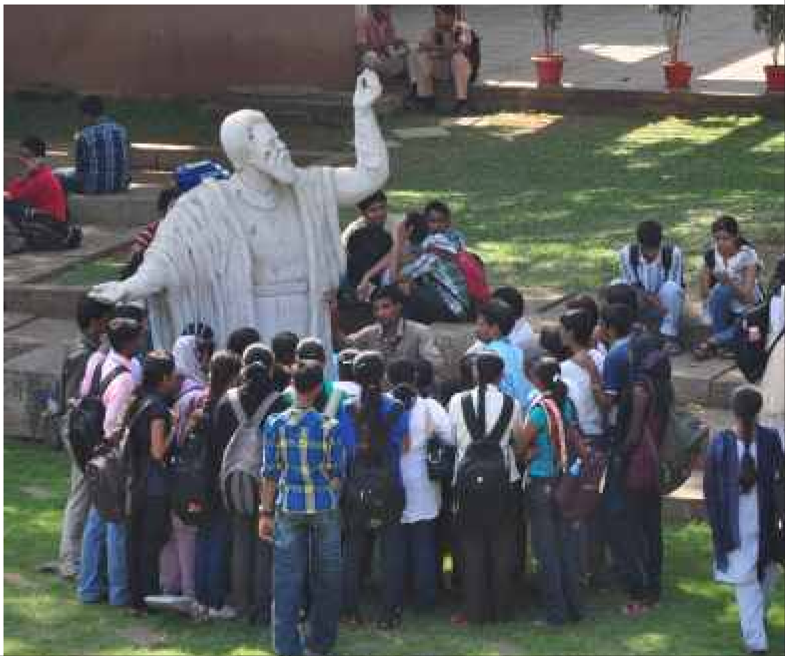
January 28 - 30
Workshop on Best Practice in Astro-Statistics
Coordinator: Ranjan Gupta and H.P. Singh

January 28 - 29
Indo-Korean Workshop on Gravitational Waves
Coordinator: Sukanta Bose

February 1 - 12
School and Workshop on Large Scale Structure: From Galaxies to the Cosmic Web
Coordinator : Aseem Paranjape

February 11 - 12
Celebrating the Discovery of Gravitational Waves

February 29 - March 3
Meeting of International Astronomical Consortium for High Energy Calibration (IACHEC)
Coordinator: Dipankar Bhattacharya



Events Outside IUCAA

2015

October 26 - 28
North East Meet of Astronomers 2015
at Tezpur University
Cooordinators: Rupjyoti Gogoi and Amit Pathak

December 2 - 6
Workshop on Novae and Accreting Binaries : A Multi-Wavelength Study
at CBS, Mumbai
Coordinators: Ranjeev Misra and Gargi Shaw

December 8 - 11
Workshop on Astronomy with Small Telescopes
at SRTM University, Nanded
Coordinator: M.K. Patil

December 10 - 12
Workshop on General Relativity at its Centennial
at CTP, Jamia Millia Islamia, New Delhi
Coordinators: Sukanta Bose and Sanjan Jhingan

2016

January 4 - 5
Workshop on Electromagnetic Light Scattering as a tool in Astronomy and Astrophysics
at M.K. Bhavnagar University, Gujarat
Coordinators: Ranjan Gupta and S.P. Bhatnagar

February 29 - March 12
School on Gravitational and Astroparticle Physics
at Central University of Himachal Pradesh (CUHP), Dharamshala
Coordinators: Tarun Souradeep and B.C. Chauhan

IUCAA Resource Centre Events

2015

July 9 - 11
Advanced Workshop on Time Domain Astronomy and Cosmology
at C.M.S. College, Kottayam, Kerala
Coordinators: Ninan Sajeeth Phillip, Joe Jacob and Ranjeev Misra

August 24 - 26
School on Gravitation and Cosmology
at CUSAT, Kochi
Coordinators: V. C. Kuriakose and Aseem Paranjape

September 10 - 12
Regional Meeting on Trends and Challenges in Astronomy and Astrophysics
at Calcutta University
Coordinators: Asis Chatopadhyay and Ranjeev Misra

November 23 - 28
Winter School on General Relativity and its Applications
at IRC, North Bengal University, Siliguri
Coordinators: Ranjeev Misra, B.C. Paul and Sanjan. Jhingan,

November 25 - 27
Workshop on Multiwavelength Astronomy and Astrophysics
at Providence Women's College, Kozhikode
(in collaboration with IRC, CUSAT, Kochi)

December 28 - January 1
National School on Gravitational Waves
at CUSAT, Kochi
Coordinators: Sanjit Mitra and V.C. Kuriakose

IUCAA Annual Events

2015

December 29
Foundation day

2016

February 28
National Science Day

Quantum Theory and Gravity

A quantum peek inside the black hole event horizon

In a recent work along with **T. Padmanabhan** and Suprit Singh, **Sumanta Chakraborty** has solved the Klein-Gordon equation for a scalar field, in the background geometry of a dust cloud collapsing to form a black hole, everywhere in the (1+1) spacetime: that is, both inside and outside the event horizon and arbitrarily close to the curvature singularity. Once the solution to the Klein-Gordon equation is known (with suitable boundary conditions ensuring that one obtains the standard black hole evaporation), the next task is to construct physically meaningful observables. There are two standard approaches which have been pursued in the literature in this context. One possibility is to introduce the particle detectors in the spacetime moving on various trajectories. Unfortunately, the response of the detector essentially measures the nature of vacuum fluctuations, and is sensitive to the history of the trajectory.

Since the primary interest is to study the effect of quantum fields on the background geometry, one needs to use a more covariant diagnostic. Such a diagnostic is provided by the regularized stress tensor expectation value, everywhere in the appropriate quantum state (viz., the Unruh vacuum) of the field. This was used to study the behaviour of energy density and the flux measured in local inertial frames for the radially freely falling observer at any given event. Outside the black hole, the energy density and flux lead to the standard results expected from the Hawking radiation emanating from the black hole, as the collapse proceeds. Inside the collapsing dust ball, the energy densities of both matter and scalar field diverge near the singularity in both (1+1) and (1+3) spacetime dimensions; but the energy density of the field dominates over that of classical matter. In (1+3) dimensions, the total energy (of both scalar field and classical matter) inside a small spatial volume around the singularity is finite (and goes to zero as the size of the region goes to zero) but the total energy of the quantum field still dominates over that of the

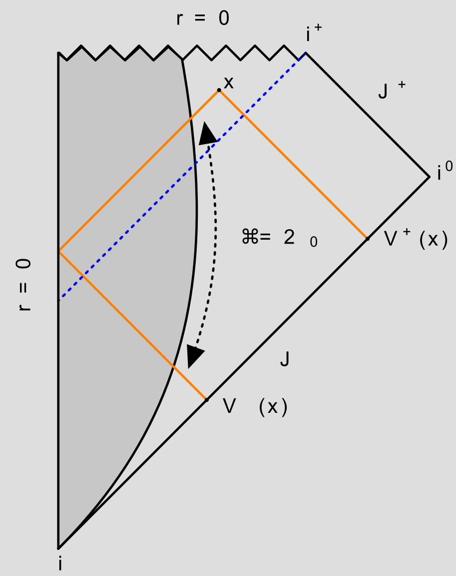


Figure 1: Penrose diagram showing the construction of double null coordinates. Each event x can be characterized by two null rays — an incoming ray from $\mathcal{J}^-$, which is labeled as V^+ and an outgoing ray, tracked backward to the vertical line $r = 0$ and then reflected towards $\mathcal{J}^-$, giving the second null coordinate V^-.

classical matter. Inside the event horizon, but outside the collapsing matter, freely falling observers find that the energy density and the flux diverge close to the singularity. In this region, even the integrated energy inside a small spatial volume enclosing the singularity diverges. This result holds in both (1+1) and (1+3) spacetime dimensions with a milder divergence for the total energy inside a small region in (1+3) dimensions. These results suggest that the back-reaction effects are significant even in the region outside the matter but inside the event horizon, close to the singularity.

Thermodynamical interpretation of null surfaces

The dynamical evolution of a fluid or a gas can be studied without any direct reference to the fact that they are made of microscopic degrees of freedom, viz., atoms and molecules. Such a description was known for centuries before physicists realized that matter is made of discrete entities. But the existence of the microscopic degrees of freedom

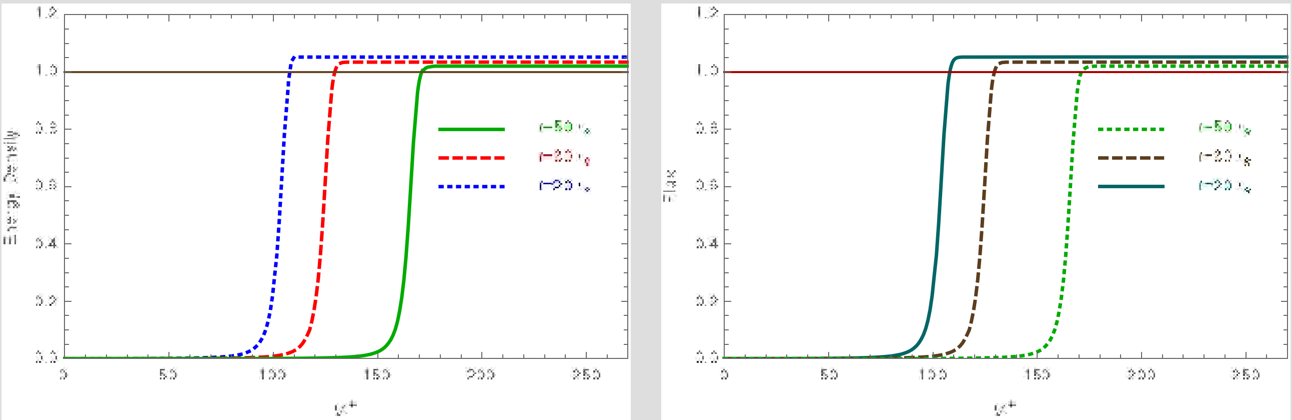


Figure 2: Variation of the energy density and the flux as observed by a static observer as a function of the proper time. The left figure shows the variation of the energy density with proper time V^+. All the static observers at different radii will ultimately observe the standard result for the Hawking radiation with the temperature modified by the Tolman redshift factor. (Note that the graphs have been normalized to their values at infinity, i.e., $\pi T_H^2/12$ for convenience.) The same situation is depicted in the right figure for the flux. Both start with a small value and then rise rapidly, ultimately saturating at the appropriate values for the Hawking radiation with the redshifted temperature.

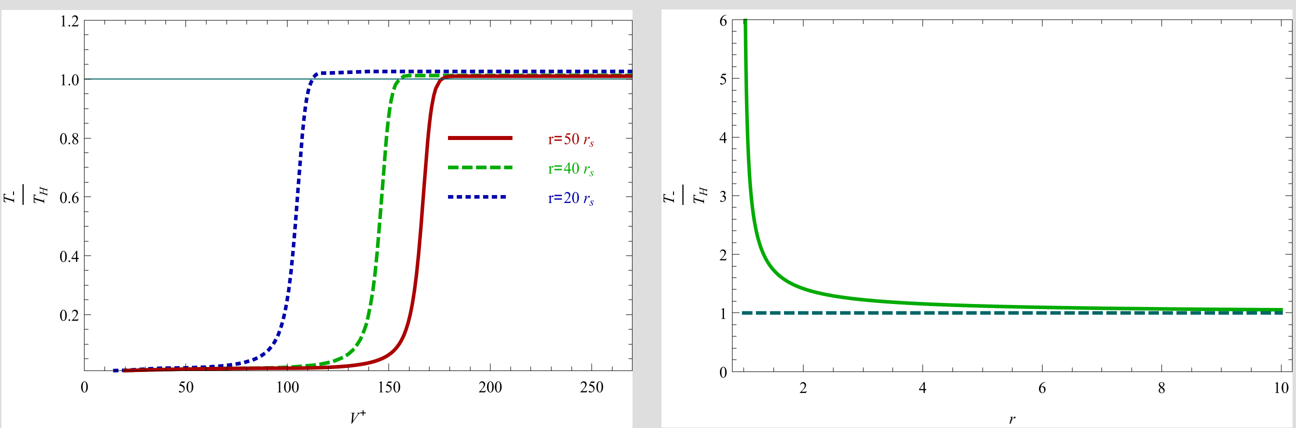


Figure 3: The effective temperature T_- reaches the Tolman redshifted Hawking temperature T_H at late V^+ (left figure). In the near horizon regime, the effective temperature T_- is positive and diverges as the horizon is approached (right figure).

had always left a clear signature even at the macroscopic scales in the form of the heat content of matter. The microscopic degrees of freedom make their presence felt even at the macroscopic scales (in the form of heat), and the correct (thermodynamic) description had taken this into account phenomenologically in terms of temperature, etc., even before Boltzmann explained what it really is. The key new element in thermodynamics, which is absent in, say, the Newtonian mechanics of point particles, is the heat content TS of the matter, which is the difference $(F - E)$ between the free energy and the internal energy of the system. In terms of densities, for systems with zero chemical potential which we are interested in, the heat density is $Ts = P + \rho$, where s is the entropy density, ρ is the energy density and P is pressure.

The emergent gravity paradigm, following the above line of arguments, interprets gravitational field equations as describing the thermodynamic limit of the underlying statistical mechanics of microscopic degrees of freedom of the spacetime. The connection is established by attributing a heat density Ts to the null surfaces, where T is the appropriate Davies-Unruh temperature. The field equations can be obtained from a thermodynamic variational principle which extremises the total heat density of all null surfaces. The explicit form of s determines the nature of the theory. In this work, along with **T. Padmanabhan**, **Sumanta Chakraborty** has explored the consequences of this paradigm for an arbitrary null surface and highlights the thermodynamic significance of various geometrical quantities. In particular, we show that: (a) A conserved current, associated with the time development vector in a natural fashion, has direct thermodynamic interpretation in all Lanczos-Lovelock models of gravity. (b) One can generalize the notion of gravitational momentum, introduced in an ealier work of **Padmanabhan**, all Lanczos-Lovelock models of gravity such that the conservation of the total momentum leads to the relevant field equations. (c) The thermodynamic variational principle which leads to the field equations of gravity can also be expressed in terms of the gravitational momentum in all Lanczos-Lovelock models. (d) Three different projections of gravitational momentum related to an arbitrary null surface in the spacetime lead to three different equations, all of which have thermodynamic interpretation. The first one reduces to a Navier-Stokes equation for the transverse drift velocity. The second can be written as a thermodynamic identity $TdS = dE + PdV$. The third describes the time evolution of the null surface in terms of suitably defined surface and bulk degrees of freedom.

Further in a recent work, **Sumanta Chakraborty**, along with **Krishnamohan Parattu** and **Padmanabhan** has shown that the gravitational field equations near any null surface in an arbitrary spacetime reduce to a thermodynamic identity, generalizing results previously available in the literature for special cases. They have shown that this is possible, by introducing (a) the temperature through surface gravity, (b) entropy density from the area and (c) the work function from the transverse metric $g^{\perp}_{ab}$. We then obtain, by projecting the Einstein's equations along the k^a direction, a relation of the form $T\delta_\lambda S = \delta_\lambda E + P\delta_\lambda V$, where the variations represent virtual displacements of the null surface along null geodesics off the surface.

They have derived their result starting from the Noether current, which shows again the intimate connection between Noether charge and thermodynamics seen in earlier works. Through this exercise, they have introduced a definition of energy, which reduces to the energy definitions introduced previously in the static case. To summarize, they have shown that for any arbitrary spacetime, without assuming any symmetry, gravitational field equations in general relativity near an arbitrary null surface reduces to a thermodynamic identity. Also, for a restricted class of spacetimes with hypersurface orthogonality enforced, the zeroth law holds (even in time dependent cases).

In a subsequent work, **Chakraborty** has provided a generalization of the above setup to Lanczos-Lovelock gravity as well. As expected, it turns out that most of the results obtained in the context of general relativity generalize to Lanczos-Lovelock gravity in a straightforward but non-trivial manner. First, they provide an alternative and more general derivation of the connection between Noether charge for a specific time evolution vector field and gravitational heat density of the boundary surface. This will lead to holographic equi-partition for static spacetimes in Lanczos-Lovelock gravity as well. Taking a cue from this, they have introduced a naturally defined four-momentum current associated with gravity and matter energy momentum tensor for both the Lanczos-Lovelock Lagrangian and its quadratic part. Then, they consider the concepts of Noether charge for null boundaries in Lanczos-Lovelock gravity by providing a direct generalization of previous results derived in the context of general relativity.

Another very interesting feature for gravity is that the gravitational field equations for arbitrary static and spherically symmetric spacetimes with horizon can be written as a thermodynamic identity near a horizon limit. This result holds in both general relativity and Lanczos-Lovelock gravity as well. In a previous work [arXiv:1505.05297], they have shown that for an arbitrary spacetime, the gravitational field equations near any null surface generically leads to a thermodynamic identity. In this work, they have also generalized this result to Lanczos-Lovelock gravity by showing that gravitational field equations for Lanczos-Lovelock gravity near an arbitrary null surface can be written as a thermodynamic identity.

Discrete quantum spectrum of black holes

The quantum genesis of Hawking radiation is a long-standing puzzle in black hole physics. Semi-classically one can argue that the spectrum of radiation emitted by a black hole looks very sparse, unlike what is expected from a thermal object. It was demonstrated through a simple quantum model that a quantum black hole will retain a discrete profile, at least in the weak energy regime. However, it was suggested that this discreteness might be an artifact of the simplicity of the eigen-spectrum of the model considered. Different quantum theories can, in principle, give rise to different complicated spectra and make the radiation from the black hole dense enough in transition lines, so as to make them look continuous in profile. **Sumanta Chakraborty** along with **Kinjalk Lochan**, shows that such a hope from a geometry-quantized black hole is not realized as long as large enough black holes are dubbed with a classical mass-area relation in any gravity theory ranging from GR, Lanczos-Lovelock to f(R) gravity. In a recent work, they have shown that the smallest frequency of emission from black hole in any quantum description is bounded from below, to be of the order of its inverse mass. That leaves the emission with only two possibilities. It can either be non-thermal, or it can be thermal only with the temperature being much larger than 1/M.

Brown-York quasi-local energy in Lanczos-Lovelock gravity and black hole horizons

A standard candidate for quasi-local energy in general relativity is the Brown-York energy, which is essentially a two dimensional surface integral of the extrinsic curvature on the two-boundary of a spacelike hypersurface referenced to flat spacetime. Several years back, **Naresh Dadhich** had conjectured that the black hole horizon is defined by equipartition of gravitational and non-gravitational energy. By employing the above definition of quasi-local Brown-York energy, along with **Dadhich**, **Sumanta Chakraborty** has verified the equipartition conjecture for static charged and charged axi-symmetric black holes. They have further generalized the Brown-York formalism to all orders in Lanczos-Lovelock theories of gravity and have verified the conjecture for pure Lovelock charged black hole in all even $d = 2m + 2$ dimensions, where m is the degree of Lovelock action. It turns out that the equi-partition conjecture works only for pure Lovelock, and not for Einstein-Lovelock black holes.

Brane world models and alternative gravity theories

Continuing the research on brane world models, **Sumanta Chakraborty** with Soumitra SenGupta has shown that metric factorizability is a valid assumption up to second order in a perturbative expansion of the brane-to-bulk curvature ratio. It should be noted that in the standard brane world models, the bulk metric ansatz is usually assumed to be factorizable in brane and bulk coordinates. However, it is not self-evident that it is always possible to factorize the bulk metric. The authors have used the gradient expansion scheme for this derivation, which involves the expansion of bulk quantities in terms of the brane-to-bulk curvature ratio, as a perturbative parameter. They also argue from their result that the same should be true for *all* orders in the perturbation scheme. They further establish that the non-local terms present in the bulk gravitational field equation can be replaced by the radion field; the effective action on the brane thereby obtained resembles the Brans-Dicke theory of gravity.

Further, **Chakraborty** with SenGupta has derived effective gravitational field equations on a lower dimensional hypersurface (known as a brane), placed in a higher dimensional bulk spacetime for both Einstein and $f(\mathcal{R})$ gravity theories. They have started their analysis on a n-dimensional bulk from which the effective field equations on a $(n-1)$-dimensional brane has been obtained by imposing Z_2 symmetry. Subsequently, they have arrived at the effective equations in $(n-2)$-dimensions starting from the effective equations for $(n-1)$-dimensional brane. Having obtained the effective field equations in Einstein gravity, they have subsequently generalized the effective field equation in a $(n-m)$-dimensional brane, which is embedded the n-dimension bulk spacetime endowed with $f(\mathcal{R})$ gravity. They have also presented applications of their results in the context of Einstein and $f(\mathcal{R})$ gravity. In both the cases, they have discussed vacuum static spherically symmetric solutions as well as solutions in a cosmological context.

Spacetime with zero point-length

It is generally believed that any quantum theory of gravity should have a generic feature - a quantum of length. **Sumanta Chakraborty**, with **T. Padmanabhan** and Dawood Kothawala, has provided a physical ansatz to obtain an effective non-local metric tensor starting from the standard metric tensor such that the spacetime acquires a zero-point-length ℓ_0 of the order of the Planck length L_P. This prescription leads to several remarkable consequences. In particular, the Euclidean volume $V_D(\ell,\ell_0)$ in a D-dimensional spacetime of a region of size ℓ scales as $V_D(\ell,\ell_0) \propto \ell_0^{D-2}\ell^2$ when $\ell \sim \ell_0$, while it reduces to the standard result $V_D(\ell,\ell_0) \propto \ell^D$ at large scales ($\ell \gg \ell_0$). The appropriately defined effective dimension, D_{eff}, decreases continuously from $D_{\text{eff}} = D$ (at $\ell \gg \ell_0$) to $D_{\text{eff}} = 2$ (at $\ell \sim \ell_0$). This suggests that the physical spacetime becomes essentially 2-dimensional near Planck scale.

Cosmic Microwave Background

The Cosmic Microwave Background (CMB) anisotropy and polarization research programme at IUCAA led by **Tarun Souradeep** and **Sanjit Mitra** has been focussed research on subtle cosmic signatures, often referred to as CMB anomalies. IUCAA team's contributed using BipoSH representation to the second set of Planck cosmology results in 2015 and developed important novel methods to further these studies in the past year. As a Planck scientist, **Mitra** has continued his key role in ongoing activities of the Planck collaboration.

Tools to study statistical isotropy of the CMB sky

The Bipolar Spherical Harmonic (BipoSH) representation proposed a decade back has been steadily established in the cosmology community as a very robust and natural measure of violation of statistical isotropy (SI) in the CMB anisotropy. Measurement of non-vanishing power in BipoSH spectra is a standard statistical technique to search for isotropy violations.

Pavan Aluri, **Nidhi Pant** and **Souradeep**, with a former student Aditya Rotti (currently a post-doc at Florida State University, U.S.A.) have developed a method to estimate signals of statistical anisotropy from a masked sky, or a partial sky, survey of CMB anisotropies. A very important aspect of such analysis is to handle masks employed to block residuals in a clean CMB map. Masking introduces additional couplings bias to the recovery. However, this procedure is generic and is also applicable to other types of signals of statistical anisotropy, such as the cosmic hemispherical asymmetry in CMB at large angular scales, weak lensing, etc. This has been employed in Planck 2015 results XVI: Isotopy and Statistics of the CMB paper. The researchers have used BipoSH estimator on Planck observed temperature map and estimated the imprints of SI violation due to our local motion and also the power asymmetry in the two hemispheres at large angular scales, which is also known as cosmic hemispherical asymmetry (CHA) (See Figure 4).

Santanu Das, Benjamin D. Wandelt and **Souradeep** have developed a new technique to make a Bayesian estimate of the underlying covariance structure of any random field on a sphere. Using this technique, a Bayesian estimate of the SI violation signal along with the posterior of the BipoSH spectra is possible from future CMB missions. In this method, Hamiltonian Monte Carlo (HMC) method is implemented to sample the distribution of BipoSH spectra. HMC is a very efficient sampling method for a higher dimensional parameter space. The robustness of this technique is verified from the simulated SI violated CMB temperature field for a few known sources like beam anisotropy and Doppler boost.

This method has been now implemented by **Aluri**, **Suvodip Mukherjee**, **Shabbir Shaikh** and **Souradeep** in collaboration with Karthik Prabhu (IISER-Pune) on Planck data to make a Bayesian estimation of the SI violation signal particularly for large angular scales CHA.

Pant, Das, Aditya Rotti, **Sanjit Mitra** and **Souradeep** have also developed an analytical technique to estimate the SI violation signal due to beam asymmetry and complex scan strategy. This analytical technique is a fast and efficient route to estimate the contribution of SI violation from instrumental systematics.

Origin and implications of the observed Cosmic Hemispherical Asymmetry

WMAP and Planck observations have indicated a violation of SI of the temperature field of CMB. Temperature fluctuations are higher at large angular scales in one hemisphere than the other hemisphere. Statistically significant deviation from SI is unacceptable in the paradigm of standard cosmology, and a complete understanding of its origin is essential to complete our cosmological model.

A possible mechanism to generate this power asymmetry is proposed by **Suvodip Mukherjee** and **Taun Souradeep**, which indicates that initial inhomogeneities during inflation with an initial fast roll phase can produce power asymmetry in the scalar perturbations and tensor perturbations. The maximum power asymmetry in tensor perturbations is much lower than the asymmetry in scalar perturbations. This method imposes a theoretical upper bound in the value of power asymmetry in the tensor perturbations.

They have proposed a new inevitable effect in B-mode polarization of CMB that can originate from an SI violated scalar perturbations. The presence of SI violated scalar perturbations can produce its imprints in the matter distribution of the Universe. Matter field causes deflection of CMB photons due to weak lensing and changes the statistics of temperature and polarization field of CMB. Imprints of CHA in matter field generates a dominant signal of SI violated lensed B-mode spectra at small angular scales, which is measurable from future CMB mission CMB-S4. This unique signal is a clinching window for the cosmological origin of this anomaly (See Figure 5).

Mukherjee, Pavan Aluri, Santanu Das, Shabbir Shaikh and **Souradeep** also have investigated the effects of CHA on cosmological parameters. Using the simulated temperature field, which is manifestly SI violated, cosmological parameters are retrieved from different patches of the sky and are compared with the full sky average value of the cosmological parameters. Lambda Cold Dark Matter (LCDM) cosmological parameters are robust and do not show significant deviation for a small amplitude of scale dependent CHA. However, for scale independent CHA, the deviation can be significant and the derived cosmological parameters can vary with the sky.

Early universe from CMB

The remarkable progress in cosmic microwave background (CMB) studies over past decade have led to the era of precision cosmology in striking agreement with the ΛCDM model. However, the lack of power in the CMB temperature anisotropies at large angular scales (low-multipole values), as has been confirmed by the recent Planck data too, is still an open problem.

Jayanti Prasad and **Tarun Souradeep**, in collaboration with Asif Iqbal and Manzoor A. Malik of the University of Kashmir, have carried out a detailed study of several inflationary models which can explain this observation. Using Monte Carlo Markov Chain (MCMC) analysis and the likelihood of Planck and WMAP, authors have constrained the inflationary parameters, which can induce a cut off in the Primordial Power Spectrum (PPS) of the scalar perturbations. This analysis sheds light into the early Universe scenarios, which can lead to the observed power suppression at large angular scales in CMB, without making any extra assumptions beyond LCDM model.

Weak lensing of CMB temperature and polarization field

Weak lensing of CMB due to large scale structure is well studied by several CMB missions. However, the lensing due to Stochastic Gravitational Waves Background (SGWB) generated during inflation is expected to generate negligible, non-detectable effects in CMB temperature and polarization field. However, several late time sources of SGWB can leave its imprints in the CMB field through weak lensing. **Shabbir Shaikh**, **Suvodip Mukherjee**, Aditya Rotti and **Tarun Souradeep** have obtained a model-independent upper bound on the energy density of the SGWB originated at different redshifts, which can be measured from future cosmic variance limited experiments. The study indicates that the B-mode is the best avenue to

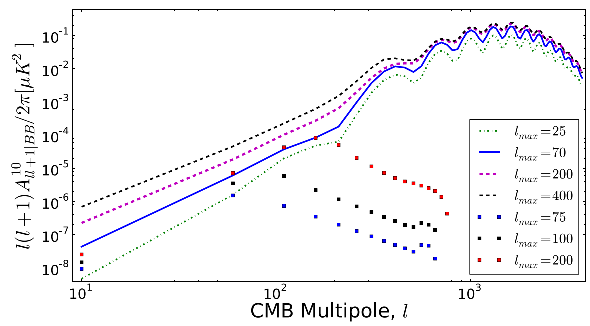


Figure 4: Nearly 3σ detection of cosmic hemispherical asymmetry from Planck temperature map using BipoSH estimator for Commander (red), NILC (orange), SEVEM (green) and SMICA (blue) independent methods of foreground removal employed by the Planck collaboration. The 1σ, 2σ, 3σ regions are plotted by different shades of grey

measure the lensing effect from SGWB. Method described in this analysis is the only currently available window to measure low-frequency gravitational waves which are sourced at very low redshifts.

Souradeep, in collaboration with former IUCAA students Moumita Aich (currently a post-doc at University of KwaZulu-Natal, South Africa) and Aditya Rotti, has developed a formalism to study the effects of weak lensing of CMB photons in a non-SI Universe. Weak lensing in the presence of an SI violated field causes an additional contribution to the angular power spectra of CMB temperature and polarization field as well as on the cosmic variance. These additional corrections to the angular power spectra can be estimated from future high-resolution CMB S4 mission and can open a new avenue to make a joint estimation of the SI violation signal in temperature or polarization field along with the lensing potential.

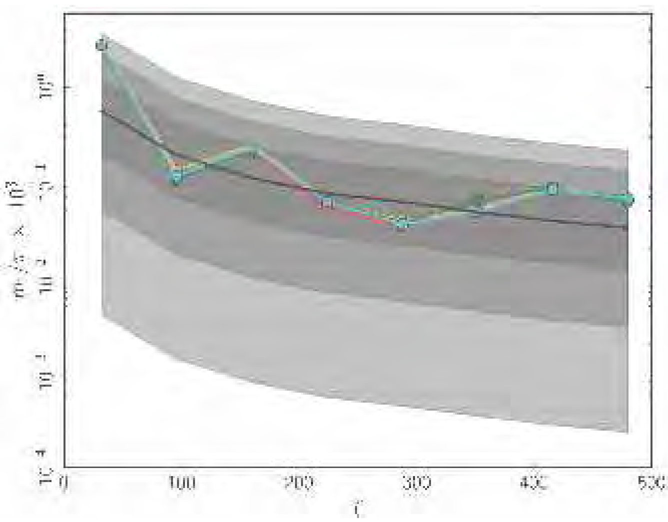


Figure 5: Imprints of cosmic hemispherical asymmetry at small angular scales in B-mode polarization due to weak lensing by SI violated large scale structure of the SI violated E-mode polarization are depicted in dashed lines for different scale dependent power asymmetry. The effect from only SI violated E-modes are plotted by squares.

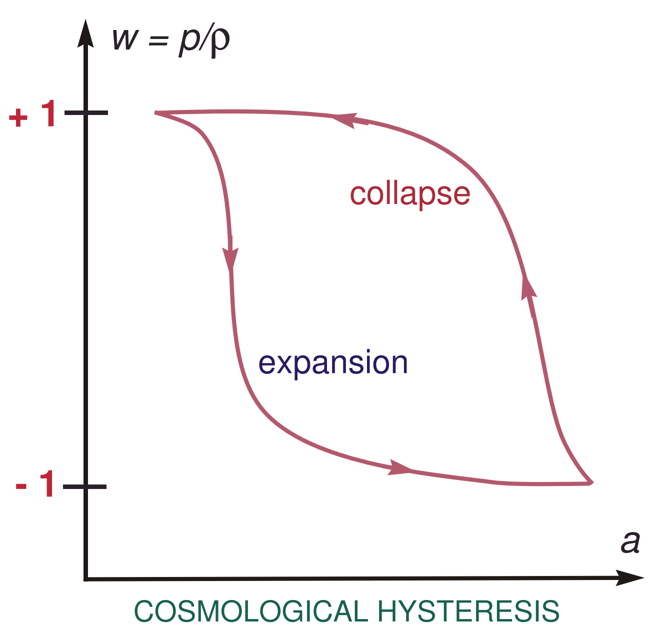


Figure 6: The hysteresis loop has $\oint p dV < 0$ evaluated over a single expansion-contraction cycle in a scalar field dominated universe.

Cosmology and Structure Formation

Arrow of time in dissipationless cosmology

It is a common and widespread belief that an arrow of time is invariably associated with some form of dissipation and entropy production which usually characterize irreversible phenomena. Indeed, in his seminal work on cyclic cosmology, Tolman introduced a viscous fluid in order to make successive expansion/contraction cycles larger than previous ones, thereby generating an arrow of time. In marked contrast, **Varun Sahni**, Yuri Shtanov and Toporensky have demonstrated that the production of entropy is not the only means by which a cosmological arrow of time may emerge. Remarkably, systems which are dissipationless may nevertheless demonstrate a preferred direction of time provided they possess attractors. An example of a system with well defined attractors is scalar-field driven cosmology. In this case, for a wide class of potentials (especially those responsible for inflation), the attractor equation of state during expansion can have the form $p \simeq -\rho$, and during contraction $p \simeq \rho$. If the resulting cosmology is cyclic, then the presence of cosmological hysteresis, $\oint p\, dV \neq 0$ during successive cycles, causes an arrow of time to emerge in a system which is formally dissipationless. This is illustrated in Figure 6, which shows how cosmological hysteresis can be associated with a scalar field in a cyclic universe. The presence of hysteresis increases the amplitude of successive expansion maxima and endows a cyclic universe with an arrow of time as illustrated in Figure 7.

They have discovered that, since the expansion factor of the universe is bounded from below, there is a typical point in trajectory space when the universe reaches the minimal value, $a = a_{\rm min} > 0$. The neighbourhood of this point can be viewed as the "origin" of the arrow of time. From this moment of time, the universe evolves with systematically increasing scale factor in both time directions. This U-shaped behaviour has been illustrated in Figure 8. **Sahni**, Shtanov and Toporensky have also demonstratd that a cyclic universe can evolve from a single past into two futures with oppositely

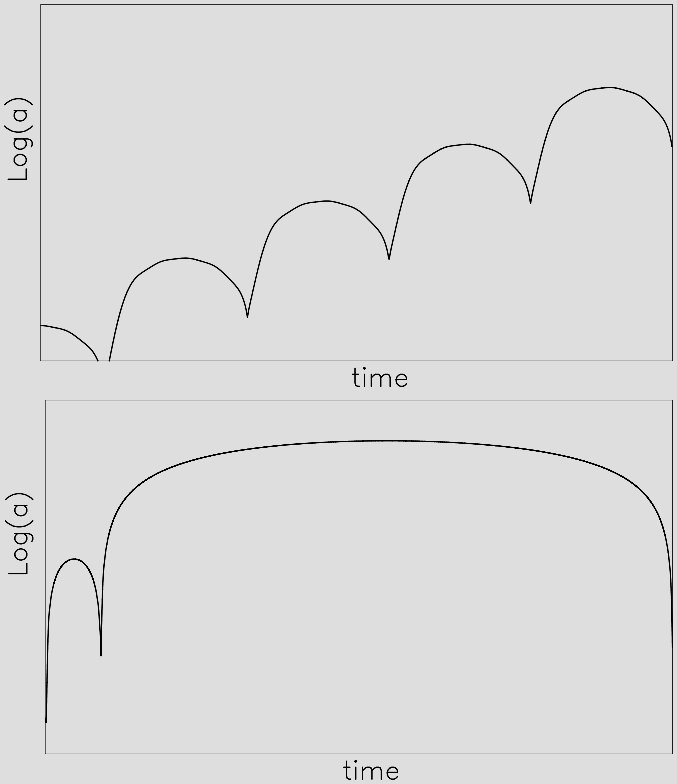


Figure 7: The presence of hysteresis, shown in Figure 6, increases the amplitude of successive expansion maxima and endows a cyclic universe with an arrow of time. In the upper panel, cosmic turnaround is caused by the presence of a negative cosmological constant, while in the lower panel, turnaround is due to the (positive) curvature term. In both panels the cyclic universe is sourced by a homogeneous scalar field with the potential $V(\phi) = \frac{1}{2}m^2\phi^2$.

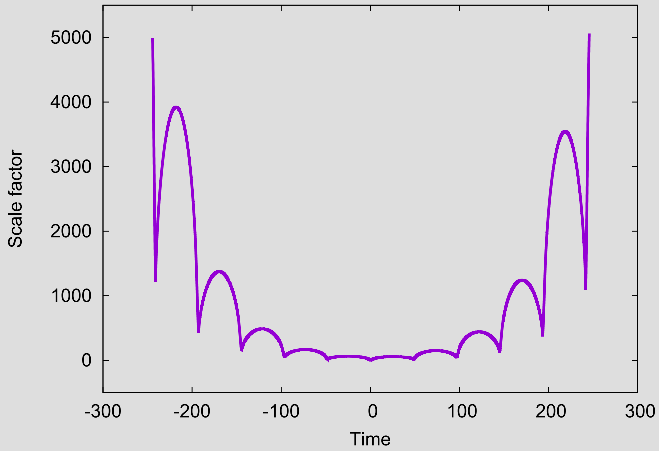


Figure 8: The expansion factor of a cyclic universe filled with a massive scalar field. The purple curve is obtained by specifying a priori initial conditions at $t = 0$ and integrating forward and backward in time. One finds that the expansion factor evolves to larger values in both time directions indicating that cosmological hysteresis is incremental ($\delta a_{\rm max} > 0$) in both cases. The qualitative behaviour of the expansion factor shown above is generic and is common to a large class of initial conditions.

directed arrows of time. Similar behaviour has been found (by other authors) for an N-body system of gravitationally interacting particles.

A new recipe for ΛCDM

Ever since the discovery that high redshift type Ia supernovae supported an accelerating universe, concordance cosmology or ΛCDM, has come to dominate popular thinking. As its name suggests, ΛCDM consists of two components: the cosmological constant Λ, and cold dark matter (CDM). Despite its enormous success in explaining observations, the origin of Λ is not known. It may simply be a residual vacuum fluctuation, although quantum field theory usually predicts much larger values, and the cosmological constant problem remains unresolved. As concerns dark matter, mainstream thinking usually assumes it to be a non-baryonic relic of the Big Bang but other explanations can also be found in the literature. Furthermore, since 96% of the content of the universe is of unknown origin, attempts have been made to describe both dark matter and dark energy within a unified setting. **Varun Sahni** and Anjan Sen have shown that a unified description of dark matter and dark energy can emerge from non-canonical scalar fields. They consider the simplest extension of the canonical Lagrangian $\mathcal{L} \propto X^\alpha - V(\phi)$, where $\alpha \geq 1$ and V is a sufficiently flat potential. In this case, the kinetic term in the Lagrangian behaves just like a perfect fluid, whereas the potential term mimicks the cosmological constant. For very large values, $\alpha \gg 1$, the equation of state of the kinetic term drops to zero and the universe expands as ΛCDM.

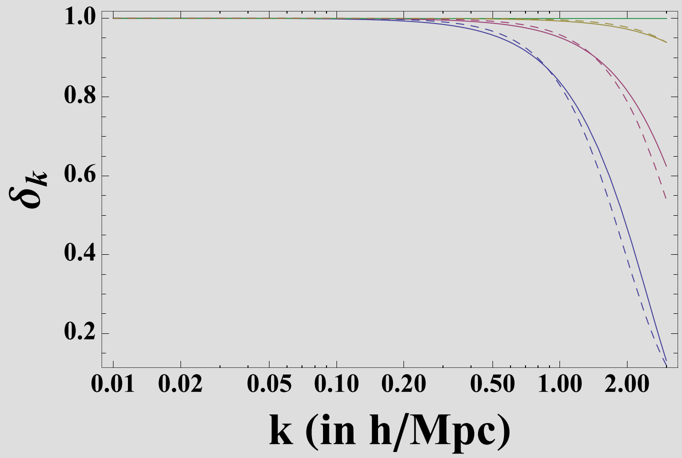


Figure 9: Perturbations δ_k, in the non-canonical scalar field model are shown at the present epoch. δ_k is plotted against k for $\alpha = 2 \times 10^7,\ 7 \times 10^7,\ 5 \times 10^8$ (bottom to top, solid lines). Perturbations in warm dark matter consisting of a sterile neutrino with mass $= 0.5, 1, 3\ KeV$ are also shown (bottom to top, dashed lines). The top most solid line corresponds to ΛCDM.

The velocity of sound in this model, and the associated gravitational clustering, are sensitive to the value of α. For very large values of α, the clustering properties of their model resemble those of cold dark matter (CDM). But for smaller values of α, gravitational clustering on small scales is suppressed, and their model has properties resembling those of warm dark matter (WDM). Therefore, the non-canonical model has an interesting new property: while the background universe expands like ΛCDM, its clustering properties can resemble those of either cold or warm dark matter (See Figure 9).

By incorporating a small scale cutoff, the model of **Sahni** and Sen can provide an alternative resolution to the cuspy core problem and the substructure problem, both of which plague the standard cold dark matter scenario.

Cosmological perturbations on the Phantom brane

Cosmology during the past two decades, has witnessed the introduction and development of several bold new theoretical ideas. One, especially radical paradigm, involves the braneworld concept. According to this, our universe is a lower-dimensional hypersurface (the 'brane') embedded in a higher-dimensional spacetime (the 'bulk'). A new feature of the braneworld paradigm, which distinguishes it from the earlier Kaluza–Klein constructs, is that spacetime dimensions orthogonal to the brane need not be compact but could be 'large' and even infinite in length. In the simplest and most thoroughly investigated cosmological models, there is only one large extra dimension accessible to gravity, while all standard-model fields are assumed to be trapped on the brane. From the viewpoint of our four-dimensional world, this manifests as a modification of gravity. In the seminal Randall–Sundrum (RS) model, gravity is modified on relatively small spatial scales.

An important class of braneworld models contains the so-called 'induced-gravity' term in the action for the brane (the 'induced-gravity' term is induced by quantum corrections from the matter fields, hence the terminology), and modifies gravity on relatively large spatial scales. Depending on the embedding of the brane in the bulk space, this model has two branches of cosmological solutions. The 'self-accelerating' branch was proposed to describe cosmology with late-time acceleration without bulk and brane cosmological constants, while the 'normal' branch requires at least a cosmological constant on the brane (called brane tension) to accelerate cosmic expansion. The self-accelerating branch was later shown to be plagued by the existence of ghost excitations. Without any additional modification, this leaves the normal branch as the only physically viable solution of this braneworld model, consistent with current cosmological observations of cosmic acceleration. The cosmology of the normal branch has been studied in detail by **Satadru Bag, Varun Sahni**, Yuri Shtanov and Alexander Viznyuk. As a model of dark energy, the normal braneworld branch exhibits an interesting generic feature of super-acceleration, which is reflected in the Phantom-like effective equation of state $w_{\rm eff} < -1$. Interestingly, the Phantom brane smoothly evolves to a de Sitter stage without running into a 'Big-Rip' future singularity typical of conventional Phantom models. Such an equation of state appears to be consistent with the most recent set of observations of type Ia supernovae combined with other data sets.

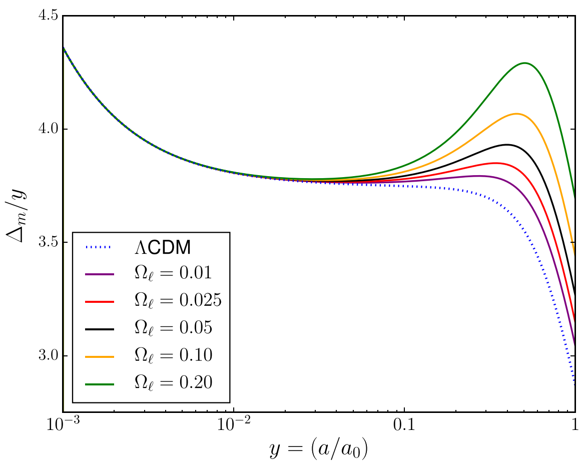


Figure 10: Density perturbations on the brane are very sensitive to the value of the brane parameter Ω_ℓ, which depends on the ratio of the five-and four-dimensional gravitational couplings. At late times, perturbations on the brane grow more rapidly than in ΛCDM (dotted blue line). The above results correspond to the scale of 10 Mpc.

The authors have obtained a closed system of equations for scalar perturbations in a multi-component braneworld. An important aspect of the braneworld is that, in addition to matter and radiation, the braneworld possesses a new degree of freedom – the 'Weyl fluid' or 'dark radiation'. Setting initial conditions on super-Hubble spatial scales at the epoch of radiation domination, they evolve perturbations of radiation, pressureless matter and the Weyl fluid until the present epoch. They observe a gradual decrease in the amplitude of the Weyl-fluid perturbations after Hubble-radius crossing, which results in a negligible effect of the Weyl fluid on the evolution of matter perturbations on spatial scales relevant for structure formation. Consequently, the quasi-static approximation of Koyama and Maartens provides a good fit to the exact results during the matter-dominated epoch. An interesting feature of gravitational instability on the brane is that the late-time growth of density perturbations on the brane proceeds at a faster rate than in ΛCDM, as shown in Figure 10.

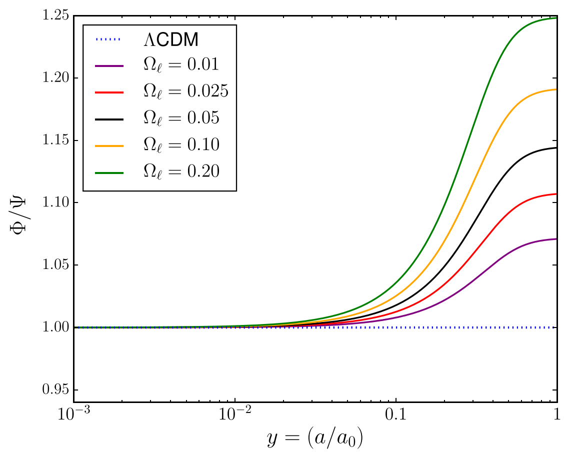


Figure 11: The evolution of the ratio Φ/Ψ is shown for different values of the brane parameter Ω_ℓ. Note that Φ/Ψ increases with Ω_ℓ, where Ω_ℓ depends on the ratio of the five-and four-dimensional gravitational couplings. By contrast, $\Phi = \Psi$ in ΛCDM (dotted blue line). Results are shown for the length scale of 10 Mpc.

Another important property of the brane which distinguishes it from ΛCDM is that the gravitational potentials Φ and Ψ evolve differently on the brane than in ΛCDM. One might note that in ΛCDM, as in other dark energy models based on general relativity, $\Phi = \Psi$ (if anisotropic matter stresses are absent). On the brane, by contrast, the ratio Φ/Ψ exceeds unity during the late matter-dominated epoch ($z \lesssim 50$) as shown in Figure 11. These features emerge as smoking gun tests of Phantom brane cosmology and allow predictions of this scenario to be tested against observations of galaxy clustering and large-scale structure.

General relativistic screening in cosmological simulations

Oliver Hahn (OCA, Nice, France) and **Aseem Paranjape** have revisited the issue of interpreting large volume cosmological simulations (which use Newtonian dynamics) in the context of large scale general relativistic effects. The standard approach involves interpreting the simulation outputs using a specific choice of variables from different gauges. The authors have clarified the situation using equations in a single gauge (conformal Newtonian), and shown that relativistic effects in fact take the form of a screening which prevents power on large scales from leaking into small scales. Their approach allows them to trivially modify standard N-body codes (by replacing the Poisson equation with a Helmholtz equation) in order to incorporate this effect. This analysis can be extended to include higher order relativistic effects using multiple fluids, which will be important for simulations used with next-generation large scale structure surveys.

HII bubbles during the epoch of reionization: Photon number conservation

Current analytical and semi-numerical models of HII bubbles lead to incorrect estimates of the total fraction of ionised mass at any given time. Fixing the problem requires carefully accounting for conservation of the number of ionising photons, which is challenging due to the stochasticity of the ionisation field. **Aseem Paranjape**, T. Roy Choudhury (NCRA) and **Hamsa Padmanabhan** (IUCAA/ETHZ) have refined existing statistical techniques to the sophistication needed to solve this problem. The resulting corrections to the HII bubble distribution potentially have important consequences for the observability and interpretation of signals expected to be seen by the SKA.

Astrobiology

ISRO has agreed to continue the experiment to sample air at heights of upto 41 km in the Earth's atmosphere. Preliminary meetings have taken place and it is expected that work will shortly begin on preparation of a balloon experiment. This experiment has been planned by **Jayant V. Narlikar** and collaborators.

Astrostatistics

Machine learning algorithms to find time delays

Large datasets are now being accumulated from long term monitoring of transient astronomical sources, and developing techniques to allow fast, automated analysis of multi-dimensional time-series has become very important. **Somak Raychaudhury**, working with Peter Tino and Sultanah al-Obaidi (Computer Science, University of Birmingham), Juan Cuevas-Tello (University San Luis Potosi, Mexico) and Ilya Mandel (Physics and Astronomy, University of Birmingham) has been developing and adapting a number of innovative machine learning algorithms for the use of astronomical data mining.

They have introduced a new probabilistic efficient model-based method for estimating time delays between two gravitationally-lensed images of the same variable point source. The method enables one to directly account for the noise levels for individual flux measurements. It is robust in the presence of inevitable observational gaps, since the imposition of an identical smooth model behind multiple lensed fluxes effectively regularizes the overall model fit, and consequently, the time delay estimate itself. This method was applied to the observed optical and radio fluxes from the two images of quasar Q0957+561 as a combined dataset. Methods such as these will be useful in the automated search for time delay systems as well as in the accurate measurement of delays in targeted systems in future very large time-domain surveys such as those planned for the Large Synoptic Survey Telescope (LSST).

Gravitational wave background in cosmological models

Jayant V. Narlikar has been continuing his work on estimating the gravitational wave background in various cosmological models. It is hoped that future experiments of gravitational wave detection will confirm or reject some of these predictions.

Gravitational Waves

The first direct observation of gravitational waves

The long quest for directly observing gravitational waves (GW), with man-made detectors, was finally rewarded when on September 14, 2015 at 09:50:45 UTC, or 15:20:45 IST, the two detectors of the Laser Interferometer Gravitational-Wave Observatory (LIGO) simultaneously observed a transient GW signal, which has come to be known as GW150914. Details of this signal were published in a paper by B. P. Abbott, et al. [LIGO Scientific and Virgo Collaborations], "Observation of Gravitational Waves from a Binary Black Hole Merger", Phys. Rev. Lett. **116**, 061102. It matches the waveform predicted by general relativity for the inspiral and merger of a pair of black holes and the ringdown of the resulting single black hole (see Figure 12). The signal was observed with a matched-filter signal-to-noise ratio of 24 and a false alarm rate estimated to be less than 1 event per 203,000 years, equivalent to a significance greater than 5.1 σ. The signal sweeps upwards in frequency from 35 to 250 Hz, and has a peak gravitational wave strain of 1.0×10^{-21}. The source lies at a luminosity distance of about 410 Mpc, corresponding to a redshift of 0.09. In the source frame, the initial black hole masses are about 36 $M_\odot$ and 29 $M_\odot$, and the final black hole mass is 62 $M_\odot$, with 3.0 $M_\odot c^2$ radiated in gravitational waves. Stellar-mass black holes this heavy have never been directly observed before. Moreover, these observations demonstrate the existence of binary stellar-mass black hole systems. Finally, this also constitutes the first observation of binary black hole merger.

Several members of IUCAA collaborated with their colleagues in the LIGO Scientific and Virgo Collaborations to contribute to GW150914. The IUCAA members are: **Sukanta Bose, Sanjeev Dhurandhar, Sanjit Mitra, Tarun Souradeep**, post-doctoral fellow, **Anuradha Gupta**, Ph.D. students, **Anirban Ain** and **Nikhil Mukund**, and visiting scientists **Jayanti Prasad** and **Sharad Gaonkar**.

Involvement of IUCAA members in this discovery spanned across a wide range of areas of this multi-disciplinary search, beginning with the basic idea used in finding the weak and short-lived gravitational wave signal in the very noisy data of the LIGO detectors. That idea, due to **Dhurandhar** and B. S. Sathyaprakash (then a post-doctoral fellow at IUCAA, now in Cardiff) from 1991, was of matching thousands of wave patterns expected from black hole binaries, with the data from the detectors. For further confirmation of the common astrophysical origin of the signals, a multi-detector consistency test was applied. The theoretical foundation for it was laid by **Bose** and **Dhurandhar**, alongwith Archana Pai (then a Ph.D. student at IUCAA, now at IISER Thiruvananthapuram). More recently, the duo, along with **Mitra**, **Gupta** and **Mukund**, carried out extensive studies towards understanding the LIGO detectors data and found ways of discerning astrophysical signals from transient terrestrial noise. They have also contributed towards developing a set of analysis tools that were used in this discovery. The High Performance Computing facility at the IUCAA Data Centre provided valuable support. Astronomers at IUCAA, led by **Varun Bhalerao**, **Javed Rana**, and **Akshat Singhal**, joined forces with their international partners to search for an afterglow soon after the gravitational wave signal was picked up by LIGO on September 14, 2015 and relayed to them subsequently. In collaboration with multiple other institutions in India and abroad, IUCAA has been leading the effort for setting up necessary mechanisms in India for electromagnetic follow-up of gravitational wave events, especially, because both kinds of signals, whenever emitted, can teach us much more about these violent phenomena in the universe than what any single kind can.

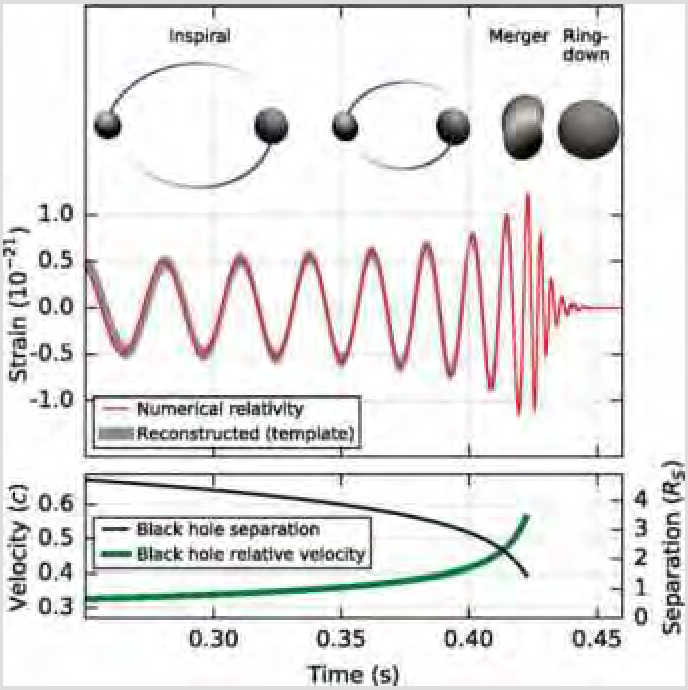


Figure 12: The top panel shows how two black holes inspiral, merge and form a big final black hole. The estimated gravitational wave signal (gray) as seen in the LIGO Hanford detector is presented below. The red curve is the result from the numerical relativity simulation of the coalescence of two black hole horizons. The bottom panel shows how the Keplerian effective black hole separation (in units of Schwarzschild radii, $R_S = 2\,G\,M/c^2$) and the effective relative velocity $v/c = (G\,M\,f/c^3)^{1/3}$ changes during the evolution of GW150914. Here, f is the gravitational wave frequency calculated with numerical relativity and M is the total mass. Figure courtesy: B.P. Abbott, et al. (LIGO Scientific Collaboration and Virgo Collaboration) Phys. Rev. Lett. **116**, 061102.

The second direct observation of gravitational waves

IUCAA scientists have also contributed to the observation of a second gravitational wave signal produced by the coalescence of two stellar-mass black holes. The signal, GW151226, was observed by the twin detectors of the Laser Interferometer Gravitational-wave Observatory (LIGO) on December 26, 2015 at 03:38:53 UTC, i.e., 09:08:53 IST. Their findings was published in B. P. Abbott, *et al.* (LIGO Scientific Collaboration and Virgo Collaboration) Phys. Rev. Lett. **116**, 241103 (2016). The signal was initially identified within 70 seconds by an online matched-filter search targeting binary coalescences. Subsequent offline analysis recovered GW151226 with a network signal-to-noise ratio of 13 and a significance greater than 5 σ (see Figure 13). The signal persisted in the LIGO frequency band for approximately 1 second, increasing in frequency and amplitude over about 55 cycles from 35 to 450 Hz, and reached a peak gravitational strain of 3.4×10^{-22}. The inferred source-frame initial black hole masses are 14.2 $M_\odot$ and 7.5 $M_\odot$ and the final black hole mass is 20.8 $M_\odot$. They find that at least one of the component black holes has spin greater than 0.2. This source is located at a luminosity distance of around 440 Mpc corresponding to a redshift of 0.09. This second observation was made within months of the first one, and showed that the September 14, 2015 discovery was not a one-off event, but that more detections can be expected to be made by these detectors in the coming years. Those observations will shed more light on how black holes and their binaries are formed.

Estimating astrophysical parameters in gravitational wave observations

Anuradha Gupta collaborated with researchers of the LIGO Scientific Collaboration (LSC) researchers to infer the final spin of the precessing binary black holes after including in-plane spins. For future observations, she has been developing tools to investigate whether any detected GW signal has experienced spin-orbit resonance or not. This in turn will help constrain the possible for-

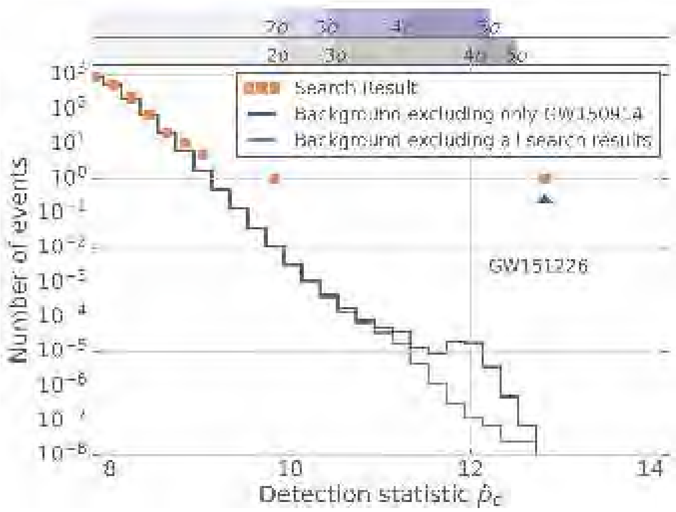


Figure 13: The search result from a detection pipeline known as pycbc. This pipeline uses combined matched filtering signal-to-noise ratio $\hat{\rho}_c$ as its statistics. The first event GW150914 is removed in the analysis, since it had already been confirmed as a real gravitational wave signal. The orange squares represent the candidate events as a function of detection statistic. The purple line shows the background estimates, excluding all the candidate events (orange squares), whereas the black lines represent the same quantity but including all the events except GW150914. The scales along the top give the significance of an event in Gaussian standard deviations based on the corresponding noise background. Figure courtesy: B.P. Abbott, et al. (LIGO Scientific Collaboration and Virgo Collaboration) Phys. Rev. Lett. **116**, 241103.

mation channels of these binaries. **Gupta** is also a reviewer in the LSC of the parameter estimation code for precessing waveforms 'SpinTaylorTx'.

Gravitational wave astrophysics, data analysis and multi-messenger astronomy

Sukanta Bose has collaborated with several international scientists on an invited submission that reviews gravitational wave sources and their detection. It was based on interactions supported by the Kavli Institute for Theoretical Physics, Beijing, during the programme on "Next Detectors for Gravitational Wave Astronomy", from April to May 2015. Importantly, this review includes results from his research pursued with IIT-Kanpur Ph.D. student Khun Sang Phukon and former IUCAA member Vihan Pandey. Among the most exciting sources of gravitational waves are coalescing binary black hole systems, as was recently vindicated by the first direct observation of gravitational waves. These systems can occur on all mass scales and be formed in numerous ways, many of which are not understood. They are generally invisible in electromagnetic waves, and they provide opportunities for deep investigation of Einstein's general theory of relativity. The work reviews a new and powerful method of signal detection based on the GPU-implemented summed parallel infinite impulse response filters. Such filters are intrinsically real time algorithms, that can be used to rapidly detect and localise signals. It also reviews the use of GPU processors for rapid searching for gravitational wave bursts that can arise from black hole births and coalescences. Finally, the work addresses the method of multi-messenger astronomy, where the discovery of electro-magnetic counterparts of gravitational wave events can be used to identify sources, understand their nature and obtain much greater science outcomes from each identified event.

Excess noise from bilinear and non-linear couplings in gravitational wave interferometers

Sukanta Bose, Sanjeev Dhurandhar and **Anuradha Gupta** have collaborated with Bernard Hall and Nairwita Mazumder (both from Washington State University) and Andrew Lundgren (AEI, Hannover) in developing tools, and using them detect excess noise in the gravitational wave (GW) channel arising from its bilinear or non-linear coupling with fluctuations of various components of a GW interferometer and its environment. They describe a higher-order statistics tool they have developed to characterize these couplings, e.g., by unraveling the frequencies of the fluctuations contributing to such noise, and demonstrate its utility by applying it to understand non-linear couplings in Advanced LIGO engineering data. Once such noise is detected, it is highly desirable to remove it or correct for it. Such action in the past has been shown to improve the sensitivity of the instrument in searches of astrophysical signals. If this is not possible, then steps must be taken to mitigate its influence, e.g., by characterizing its effect on astrophysical searches. They illustrate this through a study of the effect of transient sine-Gaussian noise artifacts on a compact binary coalescence template bank.

Low-latency mitigation of the effect of sine-Gaussian noise transients

Sukanta Bose, Sanjeev Dhurandhar and **Anuradha Gupta** have collaborated with Andrew Lundgren (AEI, Hannover) in formulating a method for improving the sensitivity of searches for gravitational waves from compact binary coalescences. Gravitational wave signals were recently detected directly by LIGO from the coalescences of two stellar mass black hole pairs. These detections have strengthened our long held belief that compact binary coalescences (CBCs) are the most promising GW detection prospects accessible to ground-based interferometric detectors. For detecting CBC signals, it is of vital importance to characterize and identify non-Gaussian and non-stationary noise in these detectors. In this work, we model two important classes of transient artifacts that contribute to this noise and adversely affect the detector sensitivity to CBC signals. One of them is the sine-Gaussian glitch, characterized by a central frequency f_0 and a quality factor Q, and the other is the chirping sine-Gaussian glitch, which is characterized by f_0, Q as well as a chirp parameter. The authors have studied the response that a bank of compact binary inspiral templates has to these two families of glitches when they are used to match-filter data containing any of these glitches. Two important characteristics of this response are the distributions of the signal-to-noise ratio (SNR) and the time-lag (i.e., how long after the occurrence of a glitch, the SNR of a trigger arising from its matched-filtering by a template peaks) of individual templates. They have shown that how these distributions differ from those when the detector data has a real CBC signal instead of a glitch. They argue that these distinctions can be utilized to develop useful signal-artifact discriminators that add negligibly to the computational cost of a CBC search and can therefore, help to improve the sensitivity of low-latency CBC searches. Specifically, they have shown how the central frequency of a glitch can be used to set adaptive time-windows around it so that any template trigger occurring in that window can be quarantined for further vetting of its supposed astrophysical nature. Second, they recommend focusing efforts on reducing the incidence of glitches with low central-frequency values, because they create CBC triggers with the longest time-lags, which makes it difficult to establish a causal connection between them.

Component separation of an isotropic gravitational wave background

Phenomena in the early universe, e.g., inflation, and unresolved/unmodelled astrophysical sources in the universe are expected to create a Stochastic Gravitational Wave Background (SGWB). Different sources can create components of SGWB with different spectral shapes. Current searches for a SGWB put upper limits separately for each component of the background. However, Abhishek Parida, **Sanjit Mitra** and Sanjay Jhingan have pointed out that one strong component will influence upper limits on the other ones, as the searches are not uncorrelated. Hence, in order to address this issue, the upper limits must be estimated jointly. They have proposed a method, which can achieve this by taking advantage of an algebraic property of the problem, thereby consuming a negligible amount of computation. The method was successfully demonstrated by applying it on (realistic) simulated backgrounds (see Figure 14).

Electromagnetic followup of gravitational wave sources

Javed Rana, Akshat Singhal and **Varun Bhalerao** have searched for possible electromagnetic (EM) counterparts to both GW150914 and GW151226. No EM counterparts have been reported for these binary black holes mergers.

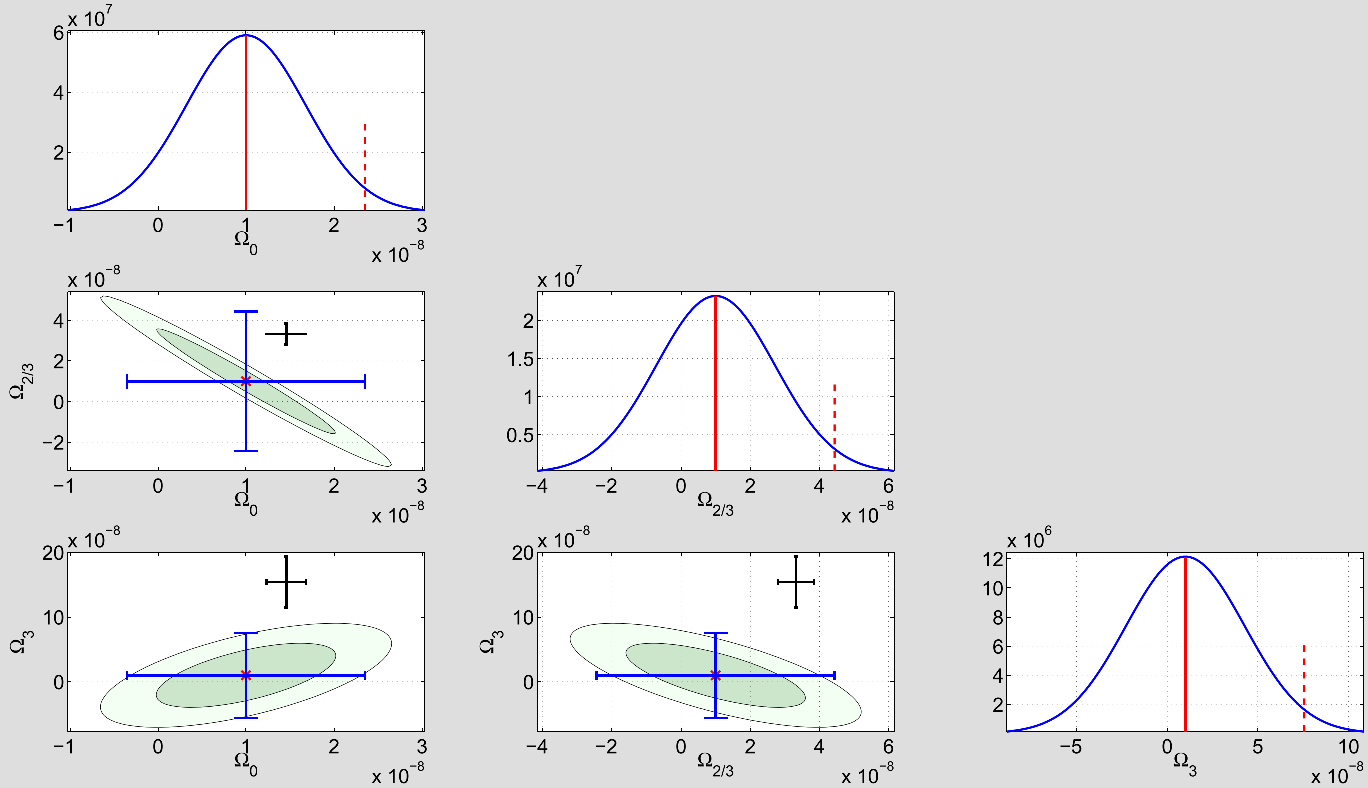


Figure 14: The estimates for amplitudes of a three component stochastic gravitational wave background with respective energy densities per unit logarithmic frequency interval $(\Omega_0, \Omega_{2/3}, \Omega_3)$, are shown. The red "×" mark shows the injected values of the parameters. A joint analysis recovers it almost exactly by construction, except for negligible numerical errors. The black (2σ) error bars show the results from a single component analysis, while the blue ones show the same from the joint analysis. The contours represent the 1σ and 2σ error ellipses, corresponding to respectively 68% and 95% confidence intervals. The one dimensional plots show the marginalised probability distributions for single parameters, where the solid vertical line represents the mean, while the dashed vertical limits indicates the 2σ upper limit. The plot illustrates that single component estimates have biased mean and error bars, and hence, the upper limits are also biased, which can be rectified by a joint analysis.

Rana, Singhal, Bhooshan Gadre, Bhalerao, and **Sukanta Bose** have explored optimal methods for scheduling observations of large sky error regions for finding optical counterparts to transients. The discovery and subsequent study of optical counterparts to transient sources are crucial for their complete astrophysical understanding. Various gamma ray burst (GRB) detectors, and more notably the ground-based gravitational wave detectors, typically have large uncertainties in the sky positions of detected sources. Searching these large sky regions spanning hundreds of square degrees is a formidable challenge for most ground-based optical telescopes, which can usually image less than tens of square degrees of the sky in a single night. They present algorithms for better scheduling of such follow-up observations in order to maximize the probability of imaging the optical counterpart, based on the all-sky probability distribution of the source position. They incorporate realistic observing constraints like the diurnal cycle, telescope pointing limitations, available observing time, and the rising/setting of the target at the observatory location. They use simulations to demonstrate that the proposed algorithms outperform the default greedy observing schedule used by many observatories. These 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.

Parameter estimation improvement

Remya Nair has collaborated with Sanjay Jhingan and Takahiro Tanaka to analyse the advantage of combining measurements of future ground and space based gravitational wave (GW) detectors in estimating the parameters of a binary coalescence. Space measurements will have sensitivity in low frequency band and hence, will act as precursors to ground measurements. They will provide much better localization information on the source and aid electromagnetic follow-up as well. Focussing on the future GW detectors, Einstein telescope and DECIGO, they have shown how the error estimates for the various parameters describing the compact binary coalescence will improve by combining the data from this pair. Since the design sensitivity of DECIGO is not fixed yet, they varied its noise sensitivity and demonstrated that there exists a sweet-spot range of sensitivities in the pre-DECIGO period, where the best enhancement due to the synergy effect can be obtained for estimates of the post-Newtonian waveform parameters. (see Figure 15).

AstroSat Mission

CZTI Images

The ability to detect and localize Gamma Ray Bursts (GRB) by the AstroSat CZT Imager payload was developed in collaboration with the AstroSat CZTI team. Three bright GRBs have been detected by this instrument during the period October 2015 - January 2016, confirming this capability.

Laboratory tests and simulations were carried out to demonstrate the capability of the AstroSat CZTI in the detection of X-ray polarisation using the angular distribution of Compton scattered events. The method developed has been put to use for GRBs and the Crab Nebula after the launch of AstroSat. Hard X-ray polarization of above 50% has been detected in the GRB GRB160131A at the energy band 100 - 250 keV. This work has been done in collaboration with members of the AstroSat CZTI team, which includes **Dipankar Bhattacharya** from IUCAA.

Calibration and characterisation of the AstroSat CZTI payload, and running the Payload Operation Centre for this instrument since the launch of AstroSat on September 28, 2015, have been the key developmental/technical survice activities performed during this period. Activities carried out at IUCAA include calibration planning, data analysis, verifion, software development and documentation.

Ultra Violet Imaging Telescope

Ultra Violet Imaging Telescope (UVIT) is one of the 5 instruments on the AstroSat satellite, which has been launched on September 28, 2015. UVIT has been designed to make images with a resolution

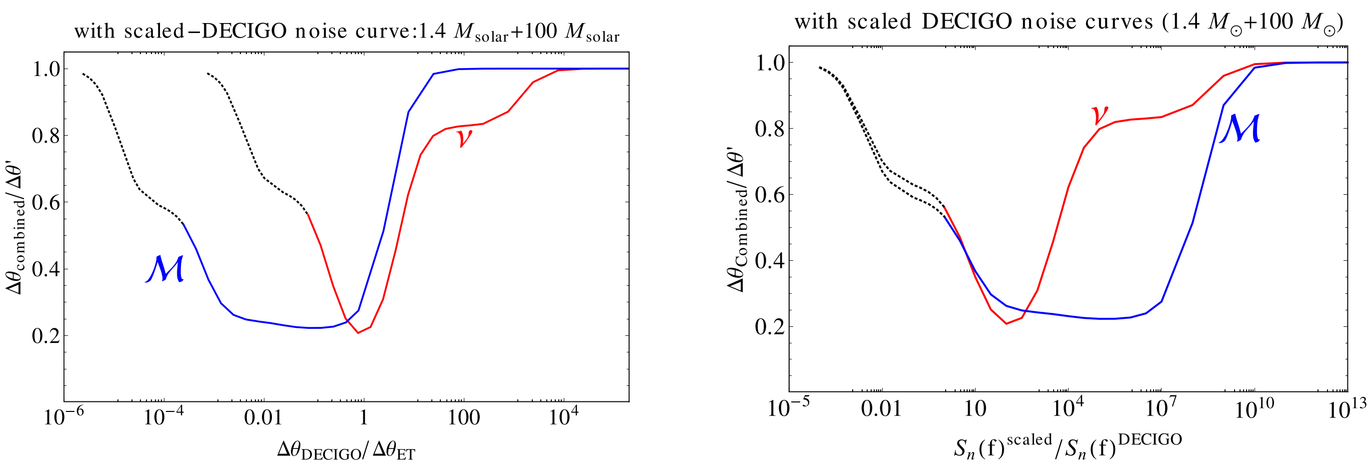


Figure 15: Variation in the error estimates of the parameters obtained by varying DECIGO sensitivities, where $\theta = \mathcal{M}$ chirp mass, or ν symmetric mass ratio. The ratio is plotted against $\Delta\theta_{DECIGO}/\Delta\theta_{ET}$ instead of $\Delta\theta_{DECIGO}$ (which varies with varying DECIGO sensitivities) to see how the scaled-DECIGO estimate compares with $\Delta\theta_{ET}$ when maximum synergy is obtained between the two measurements. The dotted curves correspond to better sensitivity than DECIGO. On the right hand panel, the horizontal axis is chosen to see how the scaled-DECIGO sensitivity compares with DECIGO sensitivity when maximum synergy is obtained between the two measurements. One can see that synergy is obtained before reaching the DECIGO sensitivity (in the pre-DECIGO phase). The two saturations in the plot that are due to the worst pre-DECIGO sensitivity (extreme right) and post-DECIGO sensitivities (extreme left) demonstrate ET dominance and DECIGO dominance in the error budget, respectively.

of < 1.8", simultaneously in three channels: Far Ultraviolet (1300 - 1800 A), Near Ultraviolet (2000 - 3000 A) and Visible (3200 - 5500 A); the total field of view is $\sim 28'$. UVIT was developed through a collaboration between several Indian institutions: IIA, ISRO, IUCAA and TIFR, and Canadian Space Agency. From IUCAA, **S. N. Tandon** has been actively working on this project. The other 4 payloads are X-ray telescopes covering energy range from $\sim$ 0.3 keV to $\sim$ 100 keV. UVIT is performing well in the orbit, and is expected to produce a large volume of excellent astronomical results over its life of 5 years. A quick view of its performance is presented below. In order to minimise any possible contaminations from the other payloads, etc. on the satellite, the doors of UVIT were only opened 2 months after the launch, and observations were made for 4 months for calibrations of the payload. Results of the calibrations show a high performance. Some key indicators of the performance are: (a) Sensitivity in 1300 - 1800 A is $\sim$ 80% of what was predicted, i.e., instrumental zero-point is AB-mag. 18.08 (this gives one detected photon per second), (b) The point spread function gives Full Width at Half maximum of < 1.6, (c) The background in 1300 - 1800 A for dark fields is $\sim$ AB mag. 26 for 10 square arcsecond solid angle, and (d) Mean relative astrometric accuracy within the field for the Near Ultraviolet detector is found to be < 0.5, which suggests bright prospects for deep imaging in which coincidences are to be found with objects seen in other images, e.g., images from ground based observations.

Science observations have just started with UVIT and there are bright prospects for exciting results on a large variety of objects, from individual stars to clusters of galaxies in sizes, including multi-wavelength observations of temporal variations in coordination with the X-ray telescopes on AstroSat (See Figure 16).

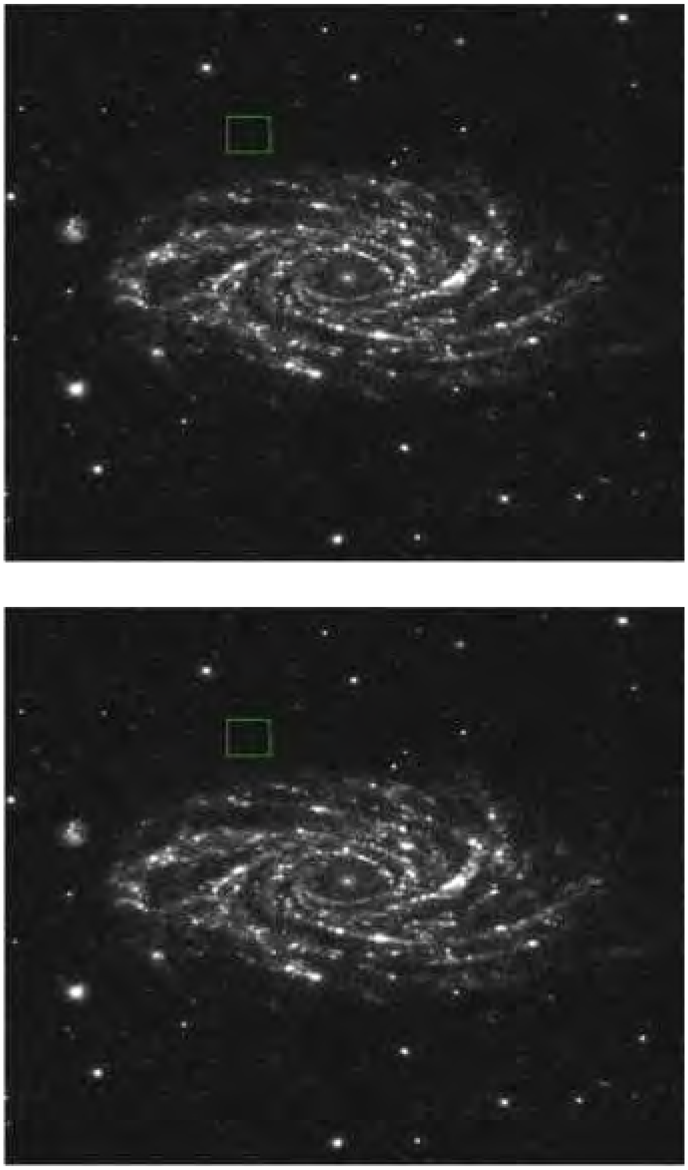


Figure 16: The top figure illustrates the spatial resolution of UVIT in Near Ultraviolet. For comparision, image of the same source by Galex (a satellite devoted to imaging in ultraviolet with a wide field of 1.2 deg.) is also shown in the bottom figure. The much higher (by ~ 3) spatial resolution of the UVIT-image is apparent.

Observational Cosmology and Extragalactic Astronomy

SALT study of pseudobulge hosting S0s

Kaustubh Vaghmare, Sudhanshu Barway, Smita Mathur and **Ajit Kembhavi** have found that pseudobulge hosting S0 galaxies have a lower disk scale length than their counterparts in spiral galaxies. They have demonstrated that this lowered scale length can be interpreted as a lower disk luminosity and have argued that this implies S0s are gas stripped spirals. Using the Southern African Large Telescope (SALT), **Vaghmare**, Barway, Vaisanen and **Kembhavi** have obtained deep long-slit spectroscopic data for a sub-sample of pseudobulge hosting S0s. Using Starlight and other custom tools developed by them, they have modelled the spectrum of these galaxies in order to study their star formation history in detail.

They have found that the nine galaxies studied in detail exhibit two distinct trends. Six of these show signs of a complex star formation history with recent star formation consistent with them being pseudobulges. However, these galaxies also show rich H-alpha emission lines indicating an active/ongoing star formation. But the lowered disk luminosity found in a previous study suggests that these were gas-stripped spirals. This is in contradiction to the observation of strong H-alpha emissions. They have argued that this most likely means that there exists some mechanism by which the gas is getting replenished, say through a wet minor merger. In the other three galaxies, they find a dominant older stellar population, contrary to the expectation one has from pseudobulge hosting galaxies. It is pointed out that all three galaxies are barred and argued that minute traces of recently formed stars indicate that these galaxies were forming a pseudobulge within the pre-existing classical bulge.

Galactic dynamics

The theme of **Arunima Banerjee's** research has been the structure and dynamics of spiral galaxies and their dark matter halos through semianalytical modelling of the cold neutral atomic hydrogen gas (HI) of the inter-stellar medium as obtained from HI 21 cm radio observations, with a special emphasis on the dark matter rich super-thin and dwarf irregular galaxies.

Redshift evolution of escape fraction of hydrogen ionizing photons from galaxies

Using the cosmological radiative transfer code, **Vikram Khaire** and **R. Srianand**, with their collaborators (T. R. Choudhury and P. Gaikwad of NCRA) have studied the implications of the updated quasar emissivity and star formation history for the escape fraction ($f_{\rm esc}$) of hydrogen ionizing photons from galaxies. They have estimated the f_{esc} that is required to reionize the Universe and to maintain the ionization state of the intergalactic medium in the post-reionization era. At $z > 5.5$, they showed that a constant f_{esc} of 0.14 - 0.22 is sufficient to reionize the Universe. At $z < 3.5$, consistent with various observations, they found that $f_{\rm esc}$ can have values from 0 to 0.05. However, a steep rise in f_{esc}, of at least a factor of $\sim$3, is required between $z = 3.5$ and 5.5. It results from a rapidly decreasing QSO emissivity at $z > 3$ together with a nearly constant measured H I photoionization rates at $3 < z < 5$. They showed that this requirement of a steep rise in $f_{\rm esc}$ over a very short time can be relaxed if the contribution from a recently found large number density of faint QSOs at $z \geq 4$ is included. In addition, a simple extrapolation of the contribution of such QSOs to high-z suggests that QSOs alone can reionize the Universe. This implies, at $z > 3.5$, that either the properties of galaxies should evolve rapidly to increase $f_{\rm esc}$ or most of the low-mass galaxies should host massive black holes and sustain accretion over a prolonged period. These results motivate a careful investigation of theoretical predictions of these alternate scenarios that can be distinguished using future observations. Moreover, it is also very important to revisit the measurements of H I photoionization rates that are crucial to the analysis presented in their work. This work is part of the PhD thesis of **Khaire**.

Elusive H I to H_2 transitions at high-z

R. Srianand and his collaborators (Pasquier Noterdaeme and Patrick Petitjean from IAP, Paris) have studied the H_2 molecular content in high redshift damped Lyman-α systems (DLAs) as a function of the H I column density. They find a significant increase of the H_2 molecular content around log N(H I)$\sim$ 21.5 - 22, a regime unprobed until now in intervening DLAs, beyond which the majority of systems have log $N(H_2) > 17$. This is in contrast with lines of sight towards nearby stars, where such H_2 column densities are always detected as soon as log N(H I) > 20.7. This can qualitatively be explained by the lower average metallicity and possibly higher surrounding UV radiation in DLAs. However, unlike in the Milky Way, the overall molecular fractions remain modest, showing that even at a large N(H I), only a small fraction of overall H I is actually associated with the self-shielded H_2 gas. Damped Lyman-α systems with very high N(H I) probably arise along quasar lines of sight passing closer to the centre of the host galaxy where the gas pressure is higher. They showed that the colour changes induced on the background quasar by continuum (dust) and line absorption (H I Lyman series and H_2 Lyman and Werner bands) in DLAs with log N(H I)$\sim$22 and metallicity $\sim$1/10 solar are significant, but not responsible for the long-discussed lack of such systems in optically selected samples. Instead, these systems are likely to be found towards intrinsically fainter quasars that dominate the quasar luminosity function. Colour biasing should in turn be severe at higher metallicities.

Cold parsec-scale gas in a $z_{abs} \sim 0.1$ sub-damped Lyman-α with disparate H_2 and 21 cm absorption

Rajeshwari Dutta, Neeraj Gupta and **R. Srianand** together with their collaborators (Sowgat Muzahid, Momjian and Charlton) have presented a detailed analysis of a H_2-bearing metal-rich sub-damped Lyman α system at $z_{abs} = 0.10115$ towards the radio-loud quasar J0441-4313, at a projected separation of 7.6 kpc from a star-forming galaxy.

The H_2, C I and Na I absorption are much stronger in the redder of the two components seen in the Hubble Space Telescope/Cosmic Origins Spectrograph spectrum. The best single-component fit to the strong H_2 component gives log $N(H_2) = 16.61 \pm 0.05$. However, possible hidden saturation in the medium-resolution spectrum can allow for log $N(H_2)$ to be as high as 18.9. The rotational excitation temperature of H_2 in this component is 133^{+33}_{-22} K. Photoionization models suggest 30 - 80 per cent of the total N(H I) is associated with the strong H_2 component that has a density ≤ 100 cm^{-3} and is subject to a radiation field that is $\leq$ 0.5 times the galactic mean field. The Very Long Baseline Array 1.4 GHz continuum image of the radio source contains only 27 per cent of the arcsecond scale emission. Using a previously published spectrum, no 21 cm absorption is found to be associated with the strong H_2 component. This suggests that either the N(H I) associated with this component is $\leq$ 50 per cent of the total N(H I) or the gas covering factor is ≤ 0.27. This is consistent with the results of the photoionization model that uses ultraviolet radiation due to stars in the associated galaxy. The 21 cm absorption previously reported from the weaker H_2 component suggests a spin temperature of $\leq$ 90 K, at odds with the weakness of H_2, C I and Na I absorption in this component. From the inferred physical and chemical conditions, they suggested that the gas may be tracing a recent metal-rich outflow from the host galaxy.

The covering fraction variability in an EUV mini-BAL outflow from PG 1206+459

R. Srianand and collaborators (Sowgat Muzahid, Charlton and Eracleous) have reported on the first detection of extreme-ultraviolet (EUV) absorption variability in the Ne VIII$\lambda\lambda$770, 780 mini-broad absorption line (mini-BAL) in the spectrum of the quasar (QSO) PG 1206+459. The observed equivalent width (EW) of the Ne VIII doublet shows a 4σ variation over a time-scale of 2.8 months in the QSO's rest frame. Both members of the Ne VIII doublet exhibit non-black saturation, indicating partial coverage of the continuum source. An increase in the Ne VIII covering fraction from $f_c = 0.59 \pm 0.05$ to 0.72 ± 0.03 is observed over the same period. The Ne VIII profiles are too highly saturated to be susceptible to changes in the ionization state of the absorbing gas. In fact, they do not observe any significant variation in the EW and/or column density after correcting the spectra for partial coverage. They, thus, propose transverse motions of the absorbing gas as the cause of the observed variability. Using a simple model of a transiting cloud, they have estimated a transverse speed of ~ 1800 kms^{-1}. For Keplerian motion, this corresponds to a distance between the absorber and the central engine of $\sim$1.3 pc, which places the absorber just outside the broad-line region. They further estimate a density of $\sim 5 \times 10^6$ cm^{-3} and a kinetic luminosity of $10^{43} - 10^{44}$ erg s^{-1}. Such large kinetic powers suggest that outflows detected via EUV lines are potentially major contributors to active galactic nuclei feedback.

Circumnuclear and infalling H I gas in a merging galaxy pair at z = 0.123

Using long-slit optical spectra obtained with the 2-m telescope at IUCAA Girawali Observatory, **R. Srianand, Neeraj Gupta** and collaborators (Momjian and M. Vivek) have shown that the radio source J094221.98+062335.2 (z = 0.123) is associated with a galaxy pair undergoing a major merger. Its companion is a normal star-forming galaxy infalling with a velocity of 185 km s^{-1} at a projected separation of 4.8 kpc. Using the Westerbork Synthesis Radio Telescope (WSRT) and Giant Metrewave Radio Telescope (GMRT), they have detected a strong H I 21 cm absorption at the systemic redshift of the radio galaxy with N(H I) $\sim 9 \times 10^{21}$ cm^{-2} for an assumed spin temperature of 100 K. Such a strong absorption is rare and has been seen only in a few compact radio sources associated with similar merging galaxy pairs. Milliarcsecond resolution Very Long Baseline Array (VLBA) observations resolve the radio source into a compact symmetric object with the hotspot separation of 89 pc. The 21 cm absorption is detected in the VLBA spectra towards both the radio lobes albeit with a strong optical depth gradient. They show that the strong 21 cm absorption is consistent with it arising from a clumpy circumnuclear disc/torus. They have also detected two weaker absorption lines redshifted with respect to the radio source in the WSRT/GMRT spectrum. These probably represent cold (i.e., T $\leq 10^{4}$ K) H I gas falling into the radio source. The presence of high concentration of H I gas in the circumnuclear regions and signature of infalling cold gas allows them to conjecture that the young radio source may have been triggered by the gas infall due to the ongoing merger.

The properties of H I gas in the outer regions of a spiral galaxy

Rajeshwari Dutta and others have studied the properties of H I gas in the outer regions ($\sim 2r_{25}$) of a spiral galaxy, UGC 00439 ($z = 0.01769$), using H I 21 cm absorption towards different components of an extended background radio source, J0041−0043 ($z = 1.679$). The radio source exhibits a compact core coincident with the optical quasar and two lobes separated by ∼7 kpc, all at an impact parameter ∼25 kpc. The H I 21 cm absorption detected towards the southern lobe has been found to extend over $\sim 2\,\mathrm{kpc}^2$. The absorbing gas shows sub-kpc-scale structures with the line-of-sight velocities dominated by turbulent motions. Much larger optical depth variations over 4 - 7 kpc-scale are revealed by the non-detection of H I 21 cm absorption towards the radio core and the northern lobe, and the detection of Na I and Ca II absorption towards the quasar. This could reflect a patchy distribution of cold gas in the extended H I disc. They have also detected H I 21 cm emission from UGC 00439 and two other galaxies within ∼150 kpc to it, that probably form an interacting group. However, no H I 21 cm emission from the absorbing gas is detected. Assuming a linear extent of ∼4 kpc, as required to cover both the core and the southern lobe, we constrain the spin temperature $<\sim 300K$ for the absorbing gas. The kinematics of the gas and the lack of signatures of any ongoing *in situ* star formation are consistent with the absorbing gas being at the kinematical minor axis and corotating with the galaxy. Deeper H I 21 cm observations would help to map in greater detail both the large and small-scale structures in the H I gas associated with UGC 00439.

High redshift galaxies

Using the Hubble Deep Field ($0.4 < z < 1.0$) observation, **Kanak Saha** has studied the evolution of pure disk systems (PDS), i.e., disk galaxies without any bulge component. It is discovered that a significant fraction ($\sim 15 - 18\%$) of disk galaxies in the HDF and in the local universe are such PDSs. The spatial distribution of light in these PDSs is well-described by a single exponential function from the outskirts to the centre and appears to have remained intact over the last 8 billion years, keeping the mean central surface brightness and scale-length nearly constant. These two disk parameters of PDSs are brighter and shorter, respectively, than those of disks which are part of disk galaxies with bulges. Since the fraction of PDSs, as well as their profile-defining parameters, do not change, this indicates that these galaxies have not witnessed either major mergers or multiple minor mergers since $z < 1$. However, there is a substantial increase in their total stellar mass and total size over the same time range. This suggests that smooth accretion of cold gas via cosmic filaments is the most probable mode of their evolutions. It is speculated that PDSs are dynamically hotter and cushioned in massive dark matter halos, which may prevent them from undergoing strong secular evolution.

The work has been reported by the editor of American Astronomical Society NOVA press as one of the most interesting aricles in extragalactic research on galaxy formation and evolution.

Origin of rotation in classical bulges

Classical bulges in spiral galaxies are known to rotate, but the origin of this observed rotational motion is not well understood. It has been shown recently that a low-mass classical bulge (ClB) in a barred galaxy can acquire rotation by absorbing a significant fraction of the angular momentum emitted by the bar. The aim here has been to investigate whether bars can also spin up more massive ClBs during the secular evolution of the bar, and to study the kinematics and dynamics of these ClBs. **Kanak Saha** has used a set of self-consistent N-body simulations to study the interaction of ClBs with a bar that forms self-consistently in the disk. He has used orbital spectral analysis to investigate the angular momentum gained by the classical bulge stars. It has been shown that the ClBs gain on average 2 - 6% of the disk's initial angular momentum within the bar region. Most of this angular momentum gain occurs via low-order resonances, particularly 5:2 resonant orbits. A density wake forms in the ClB, which corotates and aligns with the bar at the end of the evolution. The spin-up process creates a characteristic linear rotation profile and mild tangential anisotropy. The induced rotation is small in the centre, but is significant beyond 2 bulge half mass radii, where it leads to mass-weighted $V/\sigma \sim 0.2$, and reaches a local $Vmax/\sigma in \sim 0.5$ at around the scale of the bar. The resulting V/σ is tightly correlated with the ratio of the bulge size to the bar size. In all models, a box/peanut bulge forms suggesting that composite bulges may be common.

Evolution of radio galaxies: GMRT and VLA observations of the FR I radio galaxy 3C 270

The detailed study of radio galaxies has become increasingly important as they appear to be natural laboratories uniquely suited to the study of some of the most energetic phenomena in the Universe: relativistic jets arising from the associated active galactic nuclei. The radio-loud activity of the AGN in central galaxies of groups and clusters is now considered to be the most likely source of the heating mechanism injecting energy into their hot gaseous halos, thereby balancing the effects of radiative cooling, thereby making this phenomenon very important to understand.

Somak Raychaudhury, together with Konstantinos Kolokythas (University of Birmingham), Ewan OSullivan (Harvard-Smithsonian Center for Astrophysics), Simona Giacintucci (University of Maryland) has worked a detailed spectral analysis of the FR I radio source 3C 270, emanating from the nearby group-central elliptical galaxy NGC 4261, from observations at 240 MHz and 610 MHz using the GMRT, and data from the VLA at 1.55 GHz and 4.86 GHz,

Assuming equipartition of energy between the magnetic field and the relativistic particles, the radiative age of 3C 270 is estimated. Modelling multi-frequency radio data of the lobes, their radiative ages are found to be about half of the dynamical ages previously estimated from high-frequency radio and X-ray observations. The most likely interpretation of this discrepancy is that the source is the product of multiple AGN outburst, where the radiative age corresponds to the latest outburst or period of high jet power. A renewed outburst would not only inject a fresh population of young electrons in to the lobes, but would likely drive shocks, causing reacceleration. The end result would be a source whose lobe expansion time might be similar to the X-ray age estimate while the radiative age represents the onset of more recent activity (See Figure 17).

AGN activity in fossil groups and clusters

Galaxy clusters and groups are evolving systems, where the close interaction between and merging of galaxies often drive the evolution. Simulations show that galaxy mergers or instabilities caused by galaxy interactions excite gas infall and fuel the black hole growth in the central galaxies. Understanding this is also a key ingredient in knowing the recurrent AGN activity that causes the heating of the intergalactic medium. There is a class of galaxy groups and clusters, in which major mergers are thought to have taken place on timescales much larger than the recurrence of AGN activity. Such galaxy groups are known as fossil groups; these are optically dominated by a single luminous elliptical galaxy at the core of extended luminous X-ray emission similar to that seen in bright X-ray groups or clusters. Since such groups are not thought to have experienced any recent large-scale merger to have disturbed the formation of the cool core, these fos-

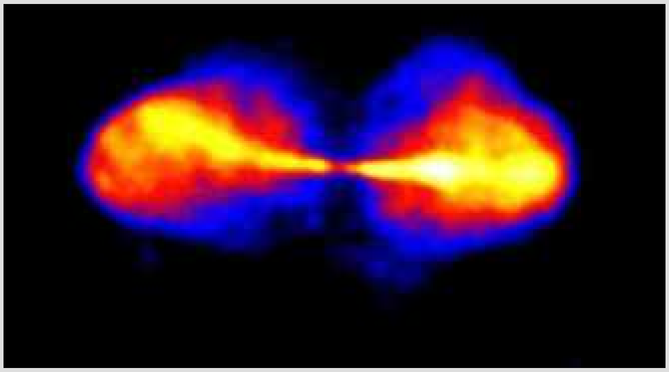


Figure 17: Image of the radio galaxy 3C 270 (NGC 4261) at 244 MHz, taken with the Giant Metrewave Radio Telescope (GMRT). The super-massive black hole at the centre of the galaxy NGC 4261 has a mass of almost 500 million suns, and has blown two jets, 300 million light years from one side to the other, consisting of particles moving at speeds close to the speed of light.

sil systems are thought to be relatively simple laboratories to study AGN feedback. Together with Halime Miraghei and Habib Khosroshahi (Institute for Research in Fundamental Sciences, Iran), and various others, **Somak Raychaudhury** has been studying fossil systems from GMRT radio observations, together with Chandra and XMM-Newton X-ray data,

From GMRT observations (610 MHz and 1420 MHz) of RX J1416.4+2315, a massive fossil galaxy group, we have estimated that the mechanical power of the weak radio lobe, and found that the energy injection into the intergalactic medium is only sufficient to heat up the central 50 kpc within the cluster core. The X-ray hardness ratio map shows three cavities within the cooling radius, which may be the results of previous AGN outbursts. The history of merging activity in these rapidly evolving systems is clearly necessary to understand the process of heating in these systems, and thus, low-frequency radio observations are very important for such studies.

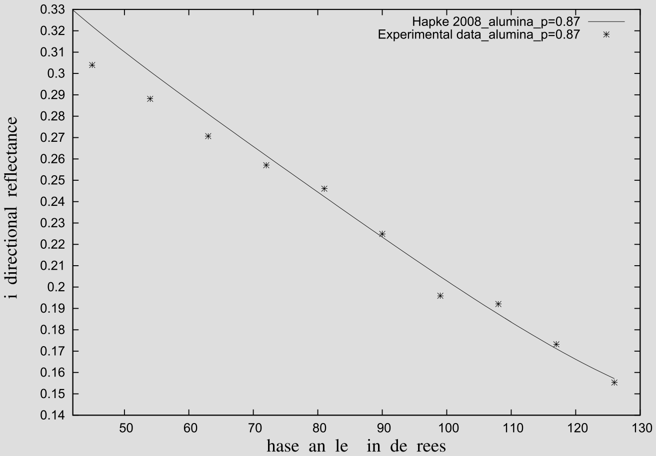


Figure 18: The UV to X-ray spectral energy distribution of RXJ1633.3+4719. The best-fitting model (solid line) has the following main components: the absorbed thermally Comptonized continuum (dotted), absorbed disc component (dotted-dashed) and unabsorbed power-law (dashed). The triangle, square, circle and crosses represent XMM-Newton U, UVW1, UVM2 filters and EPIC-pn data respectively.

High Energy Astrophysics/Active Galactic Nuclei

Accretion disc/corona and jet emission

Labani Mallick and collaborators have investigated the X-ray/UV spectral and X-ray variability properties of the radio-loud Narrow Line Seyfert 1 galaxy RXJ1633.3+4719 using XMM-Newton and Suzaku observations from 2011 and 2012. The mean X-ray spectrum consists of an ultra-soft excess component described by an accretion disc blackbody of maximum temperature ≈ 40 eV and a thermally Comptonized continuum of photon index $\Gamma_X = 2$ with a partial covering absorber of column density $N_H \approx 5 \times 10^{21} \mathrm{cm}^{-2}$ covering 65% of the X-ray emitting region. The UV spectrum is described by an unabsorbed power-law with photon index $\Gamma_{UV} \approx 3.0$, and originates from the high energy tail of the synchrotron component which can be attributed to a jet. The ultra-soft excess emission from RXJ1633.3+4719 is consistent with the standard accretion disc origin. Although the accretion disc extends down to the innermost region as implied by the ultra-soft excess emission, the absence of blurred reflection suggests lack of strong illumination of the disc by the hot corona. This could happen if the corona acts as the base of the jet and the coronal emission is beamed away from the accretion disc. Their finding of possible evidence for emission from the inner accretion disc, jet and corona from RXJ1633.3+4719 makes this object an ideal target to probe the disc-jet connection in AGN (see Figure 18). The work was done in collaboration with **Gulab Dewangan**, Poshak Gandhi (University of Southampton), **Ranjeev Misra** and **Ajit Kembhavi**.

Modelling of variability spectrum

The complexity of the broadband AGN spectra gives rise to mean spectral model degeneracy. For example, there are competing models for the broad feature near 5 – 7 keV in terms of blurred reflection and complex absorption. In order to overcome the energy spectral model degeneracy, the best approach is to study the root mean square (RMS) variability spectrum, which connects the energy spectrum with variability. The RMS spectrum determines how different spectral components change relative to each other. **Labani Mallick** in collaboration with **Gulab Dewangan** and **Ranjeev Misra** has developed an ISIS (Interactive Spectral Interpretation System) tool for RMS spectral calculation and modelling when the energy spectrum consists of a blackbody and a simple power-law. This tool is very useful to study the variability of the hot corona in AGN and can determine the correlation between slope and normalization of the coronal emission in a model independent way. They have applied their fractional variability model to the XMM-Newton observation of two AGNs: RXJ1633.3+4719 and Mrk 335. They find that the X-ray variability spectrum of RXJ1633.3+4719 is best modelled by a steady accretion disc and variable power-law primary continuum with the normalization and slope being anti-correlated by $\sim 56\%$. The variability in the slope and normalization of the primary emission are $\sim 7\%$ and $\sim 12\%$ respectively. For Mrk 335, the fractional RMS spectrum is nearly constant, independent of energy and modelled by a variable primary continuum where only power-law flux is responsible for the observed variability.

Optical/UV and X-ray variability study

Labani Mallick and collaborators have studied the short term ($\sim$ 7 days) optical/UV and X-ray variability of one broad line Seyfert 1 galaxy with XMM-Newton and NuSTAR. They find that the flux of the source in all optical/UV filters decreases gradually and follows similar trend, whereas the X-ray variability is periodic in nature over the observed time scale. The fractional variability amplitude in both the soft and hard X-ray energy bands ($F_{\rm var} \sim 4\%$) is variable but constant ($F_{\rm var,UV} \sim 0.5\%$) in the UV band on timescale of $\sim$ 7 days. The weak UV variability could be due to accretion rate variations in the accretion disc. Their analysis suggests no significant correlation between optical/UV and X-ray (soft and hard) emissions.

There is very little observational evidence to indicate that jets in radio-loud active galaxies are powered by spinning black holes. It is also not known whether there is any difference in the properties of accretion disk/corona in radio-loud and radio-quiet active galaxies, and whether the accretion discs extend to the innermost regions in radio-loud active galaxies. Ritesh Ghosh, **Gulab Dewangan** and B. Raychaudhuri have investigated some of these issues by studying X-ray and optical/UV emission from two radio-loud narrow-line Seyfert 1 galaxies and have found that the Comptonising corona is hotter in PKS0558-504 as compared to that in radio-quiet active galaxies IC4329A and Swift J2127.4+5654. They have also inferred that disc truncation at large radii and retrograde black hole spin both are unlikely to be the necessary conditions for launching the jets.

Mallick, **Dewangan**, Poshak Gandhi, **Ranjeev Misra** and **Ajit K. Kembhavi** have studied the central engines of another radio-loud narrow-line Seyfert 1 galaxy RXJ1633.3+4719. They detected an accretion disk component with inner disk temperature of kT 40eV. The UV spectrum is de-

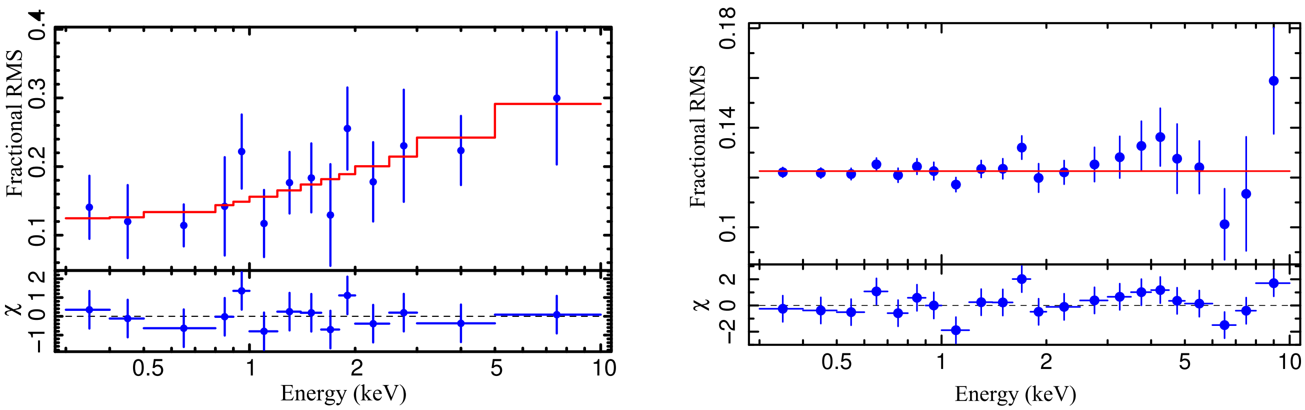


Figure 19: The fractional RMS spectra of RXJ1633.3+4719 (Left panel) and Mrk 335 (Right panel). The solid red line shows the best-fitting model to the XMM-Newton data.

scribed by a power-law with very steep photon index of about 3. The observed UV emission is too strong to arise from the accretion disc or the host galaxy, but can be attributed to a jet. The X-ray emission is variable. In contrast to radio-quiet AGN, X-ray emission from the source becomes harder with increasing flux. The fractional RMS variability increases with energy and the RMS spectrum is well described by a constant disc component and a variable power-law continuum with the normalization and photon index being anti-correlated. Such spectral variability cannot be caused by variations in the absorption and must be intrinsic to the hot corona. Their finding of possible evidence for emission from the inner accretion disc, jet and hot corona from RXJ1633.3+4719 in the optical to X-ray bands makes this object an ideal target to probe the disc-jet connection in AGN (see Figure 19).

X-ray emission from active galaxies arise from the immediate vicinity of supermassive black holes. It is thought that the observed X-ray emission carries the signature of strong gravity near the black hole. In some active galaxies, the observed X-ray spectral variability can be explained entirely by the variations in the amount of bending of light due to the changes in the height of a compact corona relative to the black hole. **Main Pal** and **Gulab Dewangan** have investigated whether the changes in the height of the corona are really the major cause of the variability of the X-ray power law continuum and the reflection. They have found a strong correlation between the soft X-ray excess and the power law components based on time-resolved spectroscopy on scales of 20,000 seconds. This is in contrast to other active galactic nuclei, where the lack of short term variation in soft X-ray excess emission has been attributed to intense light bending in the framework of the 'lamppost' model. Thus, they have inferred that the variations in power law emission are most likely intrinsic to the corona rather than just due to changes of height of the compact corona. They have also found that the variable UV emission is uncorrelated with any of the X-ray components on short time-scales. This rules out X-ray reprocessing as the dominant mechanism for the origin of the UV radiation. The gradual observed decline in the UV emission in 2012 is most likely related to the secular decline due to the changes in the accretion rate. In this case, the short term X-ray variability is not due to the changes in the seed photons but intrinsic to the hot corona.

Spectroscopic capabilities of X-ray satellites

Using the broad-band spectroscopic capabilities of two X-ray satellites SWIFT and NuSTAR, the energy spectra from a high mass black hole X-ray transient V4641 Sgr have been investigated by **Mayukh Pahari** along with **Ranjeev Misra**,

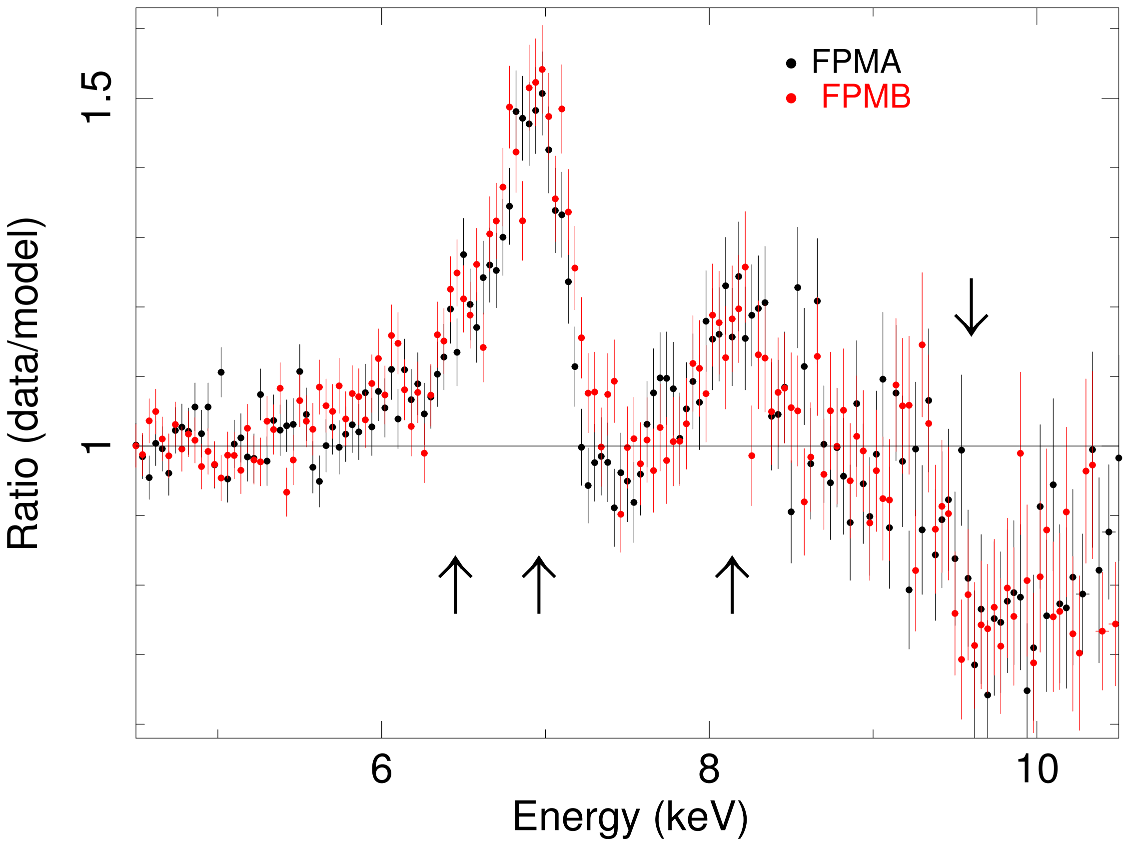


Figure 20: Data to model ratio plot in the 4.5−15.0 keV energy range for the soft state spectrum (on 2014 February 14) of V4641 Sgr is shown using simultaneous NuSTAR/FPMA (black), NuSTAR/FPMB (red) data. The continuum model that has been used to calculate the ratio is a disk emission and power law modified by the Galactic absorption. The residuals show a broad and narrow Iron lines, an emission line at ∼8.3 keV and an edge at ∼9.5 keV.

Gulab Dewangan and Pramod Pawar (SRTM University, Nanded). Using joint observations during low soft spectral state (an X-ray state where the emission is dominated by thermal black-body emission from an accretion disk), a Nickel emission line at $\sim$ 8.31 keV was identified in the energy spectra along with strong Iron emission line complex (broad, relativistically skewed line $\sim$ 6.4 keV and narrow Fe XXV emission line at $\sim$ 6.9 keV). Emission and absorption features are shown by arrows in Figure 20. Using Markov Chain Monte Carlo simulation techniques, the distance, disk inclination angle with respect to the observer and inner disk radius of the source are estimated to be $\sim$10.8 kpc, 70° and 2.4 R_g (GM/c^2) respectively. This was the first confirmed detection of the Nickel fluorescent line from any X-ray binaries.

In an attempt to understand the complex nature of energy-dependent phase lag and fractional root mean square (rms) from one of the classes, known as heart-beat oscillations or ρ class in the galactic micro-quasar GRS 1915+105, a lag model has been proposed. The model states that if the accretion disk emission during heart-beat oscillations is assumed to roughly consist of a thermal disk black-body emission plus a non-thermal power law emission, then any fluctuation in the mass accretion rate drives fluctuations in the inner disk radius after a delay time t_{d} while the power-law component responds immediately. This model, driven by pure sinusoidal oscillations, successfully explains the observed time lag and rms spectral shape and magnitude along with its reversal at $\sim$ 10 keV during the fundamental oscillation frequency. Higher order terms of the oscillations can explain the shape and magnitude of the nearly saturated time lag and rms spectra at first harmonic frequency. This work has been done by **Pahari** in collaboration with Mubashir Hamid Mir (University of Kashmir), **Misra** and other collaborators from University of Kashmir.

Studies on black hole X-ray transients

During the last decade, simultaneous optical/X-ray variability studies in X-ray binaries have become immensely important to understand the accretion and radiation mechanism in these systems at different spectral states. V404 Cyg, a black hole X-ray transient, has provided a unique opportunity in this direction upon going into simultaneous X-ray and optical outbursts in 2015. Using the ULTRACAM optical telescope, fast (millisecond) optical variabilities were observed along with slow (of the order of few hundreds of seconds) variabilities. Such fast variabilities had never been observed from any other X-ray binaries; synchrotron emission from the base of the radio jet is the only possible origin of such flares. This work has been done by **Mayukh Pahari** in collaboration with Poshak Gandhi (University of Southampton) and 26 other collaborators from different institutes of the world. With the same motivations, another hard X-ray transient GS 1354-645 (= BW Cir) has been studied using simultaneous SWIFT and INTEGRAL X-ray satellites and the SALT/BVIT optical telescope during its 2015 outburst. They have observed simultaneous optical and X-ray quasi-periodic oscillations (QPOs) in the lightcurve and have confirmed that the cyclo-synchrotron emission is the origin of optical photons from the magnetized hot flow.

Using the archival data of the Rossi X-ray Timing Explorer during high soft state or thermal dominated state observations from ten different black hole X-ray binaries, an empirical method to determine central black hole spin has been proposed. Currently existing methods to determine black hole spin highly depends on the accuracy of the estimation of fitted spectral parameters. However, the proposed method does not depend on these parameters. It assumed that during the high soft state, the accretion efficiency of corona, i.e., the fraction of mass accreting into the corona scales with the Eddington normalized accretion rate to the power $\sim$0.65. This global power law index allows one to estimate black hole spin in a simple manner. They have reproduced the black hole spin already estimated for nine different black hole systems using other methods and have predicted the black hole spin of Cyg X-3 to be $\sim$ 0.79. This work has been done by **Pahari** in collaboration with Jai Verdhan Chauhan (TIFR), **Ranjeev Misra** and Jagdish S. Yadav (TIFR).

X-ray spectral evolutions in neutron star X-ray binaries

Using simultaneous observations from SWIFT and NuSTAR, X-ray spectral evolutions in two different Atoll-type neutron star X-ray binaries has been investigated. In the broad-band X-ray spectra of 4U 1820-30, a neutron star-white dwarf binary system, the spectral fitting appears to disfavour continuum models, in which the black-body emission from the neutron star surface provides the seed photons for thermal Comptonization: Features around 6-7 keV can be well-modelled by absorption rather than by applying an Iron line emission model which is a usual practice in binary spectral fittings. From another Atoll-type neutron star X-ray binary, 4U 1728-34, four type-I X-rays bursts were detected by NuSTAR. Bursts spectra have been used to compute the neutron star radius, which is less than 11 km. Strong and variable reflection features are observed from X-ray spectra obtained during two different spectral states – island and lower banana state. This implies that reflection geometry and disk properties change at different mass accretion rates in different spectral states. Both works have been done by **Mayukh Pahari** in collaboration with Aditya Sow Mondal (Visva-Bharati, Santiniketan), **Gulab C Dewangan**, **Ranjeev Misra**, **Ajit K. Kembhavi** and B. Raychaudhuri (Visva-Bharati, Santiniketan).

Extensive analysis has been carried out using the performance verification (PV) phase data of Large Area X-ray Proportional Counter (LAXPC) on-board AstroSat, India's first multi-wavelength astronomical satellite. Calibrations using standard X-ray calibrators like Crab pulsar have been performed and using improved responses, Crab spectra can be fitted with a power-law of known index and normalization with 2% model systematics and 3% background systematics. QPOs from two black hole X-ray binaries - GRS 1915+105 and H 1743-322 have been observed at $\sim$ 3.1 Hz and $\sim$ 0.62 Hz and energy-dependent time-lag and rms spectra were obtained. They were compared with old RXTE archival data. Because of higher efficiency of LAXPC at energies $>$ 5 keV than RXTE /PCA, many interesting results have been obtained at higher energy, which have been a totally unexplored regime previously. This work by **Pahari** is currently under progress in collaboration with **Misra**, Jagdish S. Yadav (TIFR) and other LAXPC team members from TIFR, Mumbai and RRI, Bengaluru.

Cosmic Magnetic Fields

The origin, evolution and signatures of primordial magnetic fields

Kandaswamy Subramanian has written an extensive invited review for Reports on Progress in Physics on primordial magnetic fields. The universe is magnetized on all scales probed so far. On the largest scales, galaxies and galaxy clusters host magnetic fields at the micro Gauss level coherent on scales up to ten kpc. Recent observational evidence suggests that even the intergalactic medium in voids could host a weak $\sim 10^{-16}$ Gauss magnetic field, coherent on Mpc scales. An intriguing possibility is that these observed magnetic fields are a relic from the early universe, albeit one which has been subsequently amplified and maintained by a dynamo in collapsed objects. The origin, evolution and signatures of primordial magnetic fields has been reviewed. After a brief summary of magnetohydrodynamics in the expanding universe, the discussion turns to magnetic field generation during inflation and phase transitions. The linear and non-linear evolution of the generated primordial fields is traced through the radiation era, including viscous effects. Sensitive observational signatures of primordial magnetic fields on the cosmic microwave background, including current constraints from Planck, are discussed. After recombination, primordial magnetic fields could strongly influence structure formation, especially on dwarf galaxy scales. The resulting signatures on reionization, the redshifted 21 cm line, weak lensing and the Lyman-α forest are outlined. Constraints from radio and γ-ray astronomy are summarized. Astrophysical batteries and the role of dynamos in reshaping the primordial field are briefly considered. The review ends with some final thoughts on primordial magnetic fields.

A unified large/small-scale dynamo in helical turbulence

Pallavi Bhat, Kandaswamy Subramanian, and Axel Brandenburg have used high resolution direct numerical simulations (DNS) to show that helical turbulence can generate significant large-scale fields even in the presence of strong small-scale dynamo action. During the kinematic stage, the unified large/small-scale dynamo grows fields with a shape-invariant eigenfunction, with most power peaked at small scales or large k, as in **Subramanian** and Brandenburg (2014). Nevertheless, the large-scale field can be clearly detected as an excess power at small k in the negatively polarized component of the energy spectrum for forcing with positively polarized waves. Its strength $\overline{B}$, relative to the total rms field B_{rms}, decreases with increasing magnetic Reynolds number R_m. However, as the Lorentz force becomes important, the field generated by the unified dynamo orders itself by saturating on successively larger scales. The magnetic integral scale for the positively polarized waves, characterizing the small-scale field, increases significantly from the kinematic stage to saturation. This implies that the small-scale field becomes as coherent as possible for a given forcing scale, which averts the R_m-dependent quenching of $\overline{B}/B_{rms}$. These results are obtained for 1024^3 DNS with magnetic Prandtl numbers of $P_m = 0.1$ and 10. For $P_m = 0.1$, $\overline{B}/B_{rms}$ grows from about 0.04 to about 0.4 at saturation, aided in the final stages by helicity dissipation. For $P_m = 10$, $\overline{B}/B_{rms}$ grows from much less than 0.01 to values of the order of 0.2. The results confirm that there is a unified large/small-scale dynamo in helical turbulence.

Passive scalar mixing and decay at finite correlation times in the Batchelor regime

An elegant model for passive scalar mixing and decay was given by Kraichnan (1968), assuming the velocity to be delta-correlated in time. For realistic random flows, this assumption becomes invalid. Aditya K. Aiyer, **Kandaswamy Subramanian** and **Pallavi Bhat** have generalized the Kraichnan model to include the effects of a finite correlation time τ, using renewing flows. The generalized evolution equation for the 3-D passive scalar spectrum $\hat{M}(k,t)$ or its correlation function $M(r,t)$, gives the Kraichnan equation when $\tau \to 0$, and extends it to the next order in τ. It involves third and fourth order derivatives of M or $\hat{M}$ (in the high k limit). For small τ (or small Kubo number), it can be recast using the Landau-Lifshitz approach, to one with at most second derivatives of $\hat{M}$. they have presented both a scaling solution to this equation neglecting diffusion and a more exact solution including diffusive effects. To leading order in τ, they have first shown that the steady state 1-D passive scalar spectrum, preserves the Batchelor (1959) form $E_\theta(k) \propto k^{-1}$, in the viscous-convective limit, independent of τ. This result can also be obtained in a general manner using Lagrangian methods. Interestingly, in the absence of sources, when passive scalar fluctuations decay, they have shown that the spectrum is of the form $E_\theta(k) \propto k^{1/2}$ and also independent of τ. The decay rate is, however, reduced for finite τ. They have also presented results from high resolution (1024^3) direct numerical simulations of passive scalar mixing and decay. They have found reasonable agreement with predictions of the Batchelor spectrum, during steady state. The scalar spectrum during decay is, however, shallower than what theory predicts, a feature which remains intriguing.

Interstellar Medium and Galaxies

Silicate features in circumstellar dust

In continuation of the work on modelling silicate $10\mu m$ feature, **Ranjan Gupta** and collaborators have fitted the IR spectra with new models (Si+SiC) and have also attempted to fit some of the Spitzer data. This work is in progress and Figure 21 shows their dust model fits to the Spitzer data.

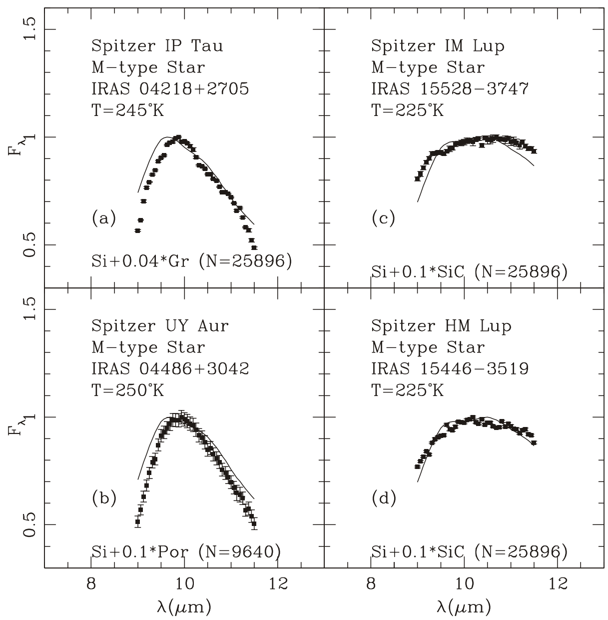


Figure 21: Best fits to a set of Spitzer observed spectra. The solid points with error bars are the Spitzer data and continuous line is the best fit model.

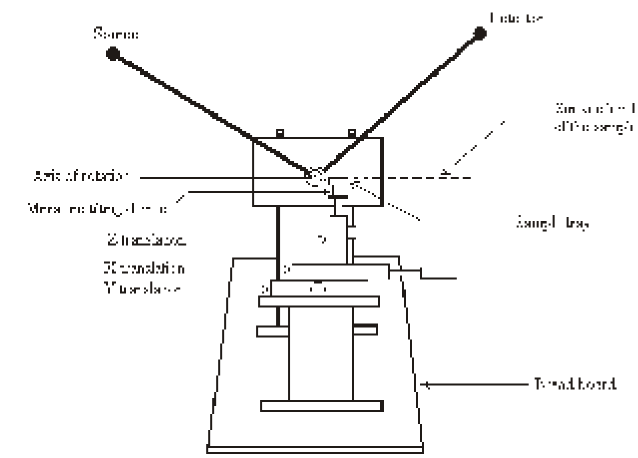


Figure 22: A schematic diagram of the goniometric device used in the experiment.

Laboratory studies of regolith analogues

In a recent study with collaboration of IUCAA Visiting Associate, A.K. Sen (and his student Amritaksha Kar) from Assam University, Silchar, **Ranjan Gupta** has carried out a study of the effect of porosity on reflectance as a function of phase angle for grain size having dimension about half, twice and those larger than the illuminating wavelength. The experimental setup used for generating reflectance data is a goniometric device developed at the Department of Physics, Assam University, Silchar, in collaboration with IUCAA. It has been found that, the porosity has a distinguishable effect on reflectance and the contribution of multiple scattering function for different porosity is examined.

More details of this work is provided in the reference which is currently under review at the ICARUS journal (see Figures 22, 23, 24, and 25). It is to be noted that laboratory light scattering studies of regoliths is a powerful tool to study the planetary regoliths and compare with spacecraft ob-

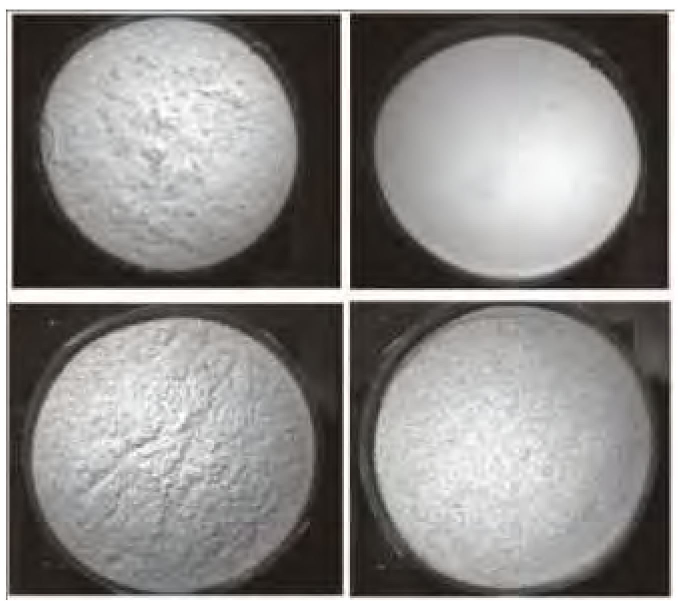


Figure 23: Pictures of sample powders. Upper panel showing 0.3 μm sized alumina powder under fluffy (left) and compact (right) conditions. Whereas lower panel shows 49 μm olivine powder under fluffy (left) and compact (right) condition.

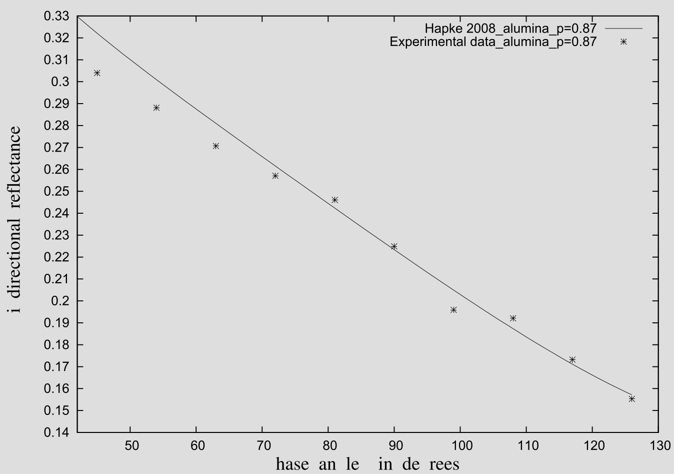


Figure 24: Reflectance of light scattered from rough surface containing 0.3 μm alumina powder having porosity 0.87 is shown as a function of phase angle. Stars represent the laboratory data points and the solid line represents model curve. Each data point is an average of four measurements.

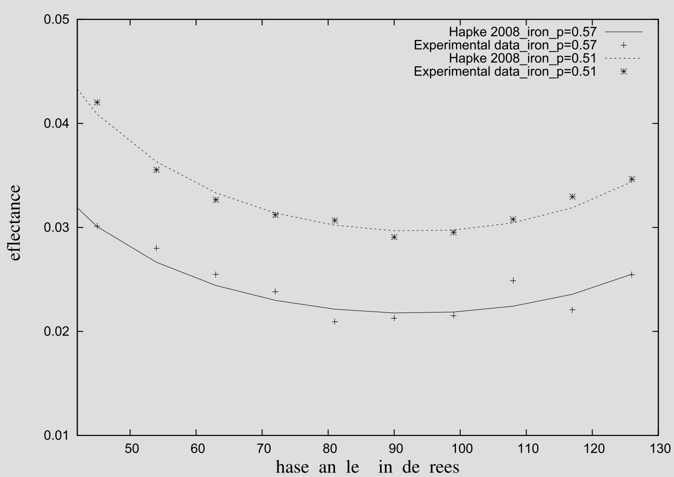


Figure 25: Reflectance curves for 45 μm iron powder with porosities of 0.57 and 0.51.

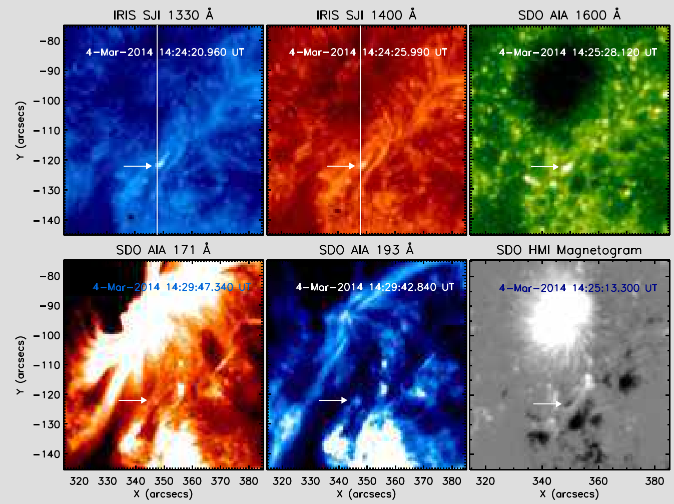


Figure 26: The location of explosive event marked with arrows detected in slit-jaw images of IRIS 1330 Å, 1400 Å, and AIA/SDO 1600 Å 171 Å, and 193 Å images as labeled. The corresponding HMI/SDO magnetic field map is also shown in bottom right most panel. The vertical white continuous line on the top of IRIS slit-jaw images represents IRIS spectroscopic slit position which is passing through the EE studied here.

servations of surfaces of planets, asteroids, etc.

Solar Astrophysics

Recurrent explosive events and jets in the solar atmosphere

Heating of the upper solar atmosphere is one of the most important problems in astrophysics. Magnetic field is believed to play an important role in the heating of upper atmosphere. Solar atmosphere is highly inhomogeneous and shows changes on a time scale of a few minutes. It is proposed that several small-scale magnetic reconnection events may lead to the release of energy in the form of nanoflares or microflares and heat the solar atmosphere. In that regard, various small scale energetic phenomena have been observed in the solar atmosphere such as explosive events, jets, etc. and are suggested to play major roles in transporting mass and energy to solar corona.

Recently, **Girjesh Gupta** and **Durgesh Tri-**

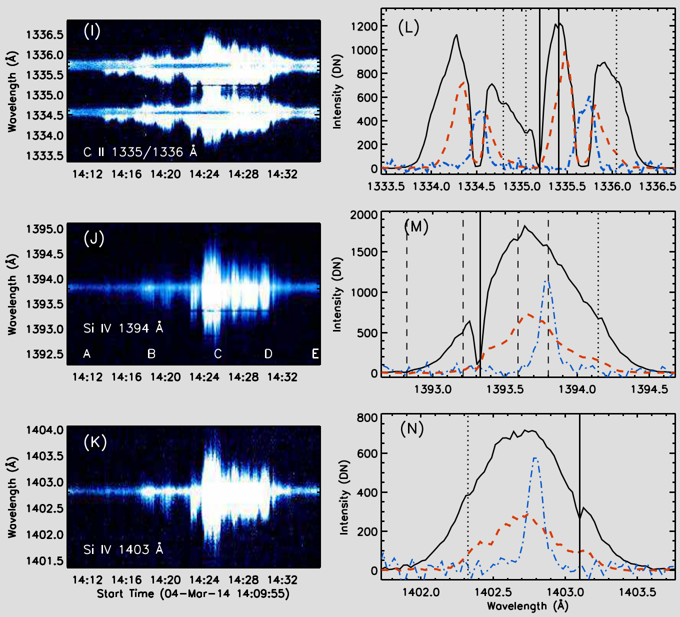


Figure 27: Wavelength-time plot of the observed explosive events in C II 1335/1336 Å doublet, Si IV 1394 Å and 1403 Å spectral lines (panels I, J and K). Typical spectral line profiles at various locations are shown in panels L, M and N, where continuous lines show the line profile at the peak of event (position C in panel J), dot-dash line indicates profile during the quiescent time (position A in panel J), and dashed line is for intermediate time (position D in panel J). Vertical continuous and dashed lines in panels L, M and N indicate most prominent and less prominent absorption lines from known ions, whereas dotted lines indicate absorption features from unknown ions.

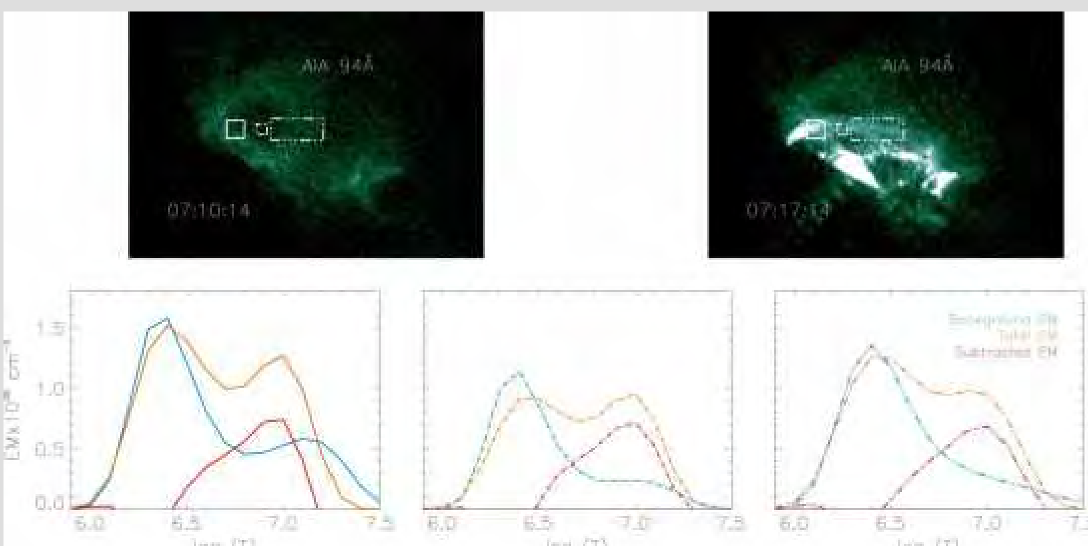


Figure 28: Evolution of an active region jet on 02-August-2010 from AR 11092 in all AIA passbands. Note that different channels are sensitive to different temperatures. The presence of multi-thermal plasma is revealed.

pathi have observed recurrent explosive events (EEs) occurring with time scale of $\sim 3 - 5$ min using imaging and spectroscopic instruments (see Figure 26). The observed spectral line profiles showed strong broadening in both red and blue wings during the EEs. On top of the broadened spectral profile, several absorption lines have been identified. This fact suggests that the EEs are occurring within the cooler atmosphere (see Figure 27). This is for the first time a short-period variability (30 s and $60 - 90$ s) within individual EE bursts. Observations of photospheric magnetic field underneath EEs have indicated that negative polarity field emerged in the neighbourhood of oppositely directed positive fields that underwent repetitive magnetic flux cancellation. The results suggest that EEs are formed due to magnetic reconnection, occurring in the lower solar atmosphere and can contribute to the heating of the solar atmosphere.

Flux ropes

Flux ropes are helical structures often seen in the core of coronal mass ejections (CMEs). In fact, the presence of flux ropes in CMEs are considered to be very important for them to be geo-effective. Most of the CMEs have been observed in white-light, and it has, therefore, been a challenge to work out the proper thermal structure of flux ropes. With the launch of SDO, the AIA images are providing opportunities to study the temperature structures in details.

Aparna Venkataramanasastry and **Durgesh Tripathi** have studied a filament eruption event that was clearly associated with a flux rope. A novel technique has been used to remove the contribution of the cooler temperature plasma from AIA 94 Å channel. The resultant images of 94 Å have shown that the flux rope has significant contribution from Fe XVIII emission. The contribution from hot plasma in flux ropes has been further proved using emission measure analysis of the LOS emission before and during the observation of the flux rope (see Figure 28).

A new method to analyze the spectral data

A lot of valuable information can be obtained from the shapes of spectral line profiles about the gas that is emitting. The shape of the line profile is especially important when it contains information on ensemble of structures amalgamated along the LOS. In general, important information is lost if the spectral resolution of the instrument is not good enough. **Durgesh Tripathi** along with his collaborators has developed an iterative procedure that provides the line profile by preserving the information lost due to spectral resolution. This procedure converges rapidly and can be used by any fitting function such as Gaussian or cubic spline.

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96. M. Vivek, **R. Srianand** and **Neeraj Gupta** (2016) *Transient C IV broad absorption lines in radio-detected QSOs,* MNRAS, **455**, 136.

97. J. A. Klimchuk, S. Patsourakos and **Durgesh Tripathi** (2016) *Intensity conserving spectral fitting*, Sol. Phys., **291**, 55.

98. **Kaustubh Vaghmare**, Sudhanshu Barway, Smita Mathur and **Ajit Kembhavi** (2015*) Spiral galaxies as progenitors of pseudo-bulge hosting S0s*, MNRAS, **450**, 873.

99. **Aparna Venkataramanasastry** and **Durgesh Tripathi** (2016*) A hot flux rope observed by SDO/AIA,* Ap. J., **819**, 71.

(B) PROCEEDINGS

1. Ruta Kale, K. S. Dwarakanath, Dharam Vir Lal, **Joydeep Bagchi**, Surajit Paul, et al. (2016*) Clusters of galaxies and the cosmic web with SKA; SKA India Science,* Version 2, 73.

2. A. Surendran, **Mahesh Burse**, **A.N. Ramaprakash** and P. Parihar (2015) *Development of a scalable generic platform for adaptive optics real time control,* Procds. Intl. Conf. Opt. Photo., **9654**, 965425.

3. **Gulab Chand Dewangan**, P.K. Pawar and **Main Pal Rajan** (2015) *X-ray/UV variability of narrow-line Seyfert 1 galaxies,* ASInC, **12**, 57.

4. **Jayant V. Narlikar** (2015) *What a student can learn from the Saha equation?*, Applied Mathematics, Springer Procds. Mathematics and Statistics, Eds. S. Sarkar, U. Basu and S. De, **146**, 89.

5. **Main Pal Rajan, Gulab Chand Dewangan, Ranjeev Misra** and P.K. Pawar (2015) *Complex optical/UV to X-ray spectral variability of 1H 0419-577,* ASInC, **12**, 143.

6. C. Baranec, ..., **A.N. Ramaprakash**, et al. (2015*) World-wide deployment of Robo-AO visible-light robotic laser adaptive optics systems*, Procds. IAU General Assembly 22, 2255576.

7. Jan M. Vrtilek, Ewan O'Sullivan, Konstantinos Kolokythas, Laurence Paul David, ... and **Somak Raychaudhury** (2015) *The Complete Local-Volume Groups Sample (CLoGS): Progress in the unbiased assessment of galaxy group physics and evolution,* Procds. IAU Gen. Assem. Meet., No. 29, id. 2258272.

8. James A. Klimchuk, Spiros Patsourakos and **Durgesh Tripathi** (2015) *Intensity Conserving Spline Interpolation (ICSI): A new tool for spectroscopic analysis,* Procds. Joint AAS/AGU Triennial Earth-Sun Summit 1, **203**, 09.

9. **Kaustubh Vaghmare**, Sudhanshu Barway, P. Vaisanen and **Ajit K. Kembhavi** (2015) *Star formation histories of S0 galaxies,* Procds. SALT Science Conf., Special Issue.

(C) BOOK AUTHORED

T. Padmanabhan
Quantum Field Theory: The Why, What and How
Springer, Heidelberg (2016)

(D) BOOK REVIEWED

Jayant V. Narlikar

Indian Astronomy - Concepts and Procedures, by S. Balachandra Rao and Ganita Bharati
Bulletin of the Indian Society for History of Mathematics, **36,** 2, 205, (2015).

(E) POPULAR ARTICLES

Jayant V. Narlikar
Tarkashuddha yuktivad: Kahi majedar udaharana! (in Marathi) (*Logical reasoning: Some interesting examples!*), Saptarang, Sakal, April 5, 2015.

Challenge the ego, The Asian Age, April 8, 2015.
Gunanchi kadar hotech... (in Marathi) (*Virtues are rewarded in the end?*), Saptarang, Sakal, May 3, 2015.

The gender games geniuses play, The Asian Age, May 8, 2015.
Probity begins at home, The Asian Age, June 3, 2015.

Adhikar ani jababdarya (in Marathi) (*Privileges and responsibilities*), Saptarang, Sakal, June 7, 2015.

Guardians of our galaxy, The Asian Age, July 3, 2015.
Ganit ani vyuharachana (in Marathi) (*Mathematics and mazes*), Saptarang, Sakal, July 5, 2015.

The maze and the magic of numbers, The Asian Age, July 29, 2015.
Yogya aakarache mahatva (in Marathi) (*Why size is important?*), Saptarang, Sakal, August 2, 2015.

Kepler-452b : A space odyssey, The Asian Age, August 27, 2015.
Gurutvakarshanachi kimaya (in Marathi) (*The wonders of gravitation*), Saptarang, Sakal, September 6, 2015.

Relativity and comedy of errors, The Asian Age, September 23, 2015.
Kam bandh; sutti chalu (in Marathi) (*Nation on a holiday*), Saptarang, Sakal, October 4, 2015.

The rhyme of reason and logic, The Asian Age, October 30, 2015.
Mahatva Astrosatcha (in Marathi) (*The importance of AstroSat*), Saptarang, Sakal, November 1, 2015.

Science is not free from errors, The Asian Age, November 12, 2015.
Jevha vaidnyanik chuka kartat... (in Marathi) (*When scientists make mistakes*), Saptarang, Sakal, December 6, 2015.

A rebel genius, The Asian Age, December 16, 2015.
Dnyan-vidnyan ke kshetra mein Hindi, (in Hindi) (*Hindi in the areas of knowledge and science*) (2015) Chintan ki vividha dishayein, 36.

Krishna vivar (in Hindi) (*Black hole*) (2015) Electroniki aapke liye, 17.
Vidnyan keval matrubhasha mein hi padhaya jana chaiye (in Hindi) (*Science should be taught in mother tongue only*) (2015)

Rashtrabhasha (August - September Issue), 36.
Dialogue between father and daughter (in Marathi) (2015) Sanvad Baaplekincha, page 12 (Supplement).

IUCAA aani Correa (in Marathi) (*IUCAA and Correa*) (2015) Marathi Vidyan Parishad Patrika (August Issue), 12.

Vyapak sapekshata (in Marathi) (*General relativity*) (2015) Marathi Vidnyan Parishad Patrika (November Issue), 91.
Ganit aani chakravyuha (in Marathi) (*Mathematics and the mazes*) (2015) Dharmabhaskar (Diwali Issue), 80.

Char nagarantale char pavsale (in Marathi) (*Four rains in four cities*) (2015) Bhavatal (Diwali Issue), 76.

Fred Hoyle: Shatak gajavnara shastradnya (in Marathi) (*Fred Hoyle: Whose centenary is being celebrated*), Saptarang, Sakal, January 3, 2016.

Cambridge tales, The Asian Age, January 13, 2016.
'Pauranik vidnyan' an puravyancha nikash (in Marathi) (*Ancient science and evidence for it*), Sakal, January 30, 2016.

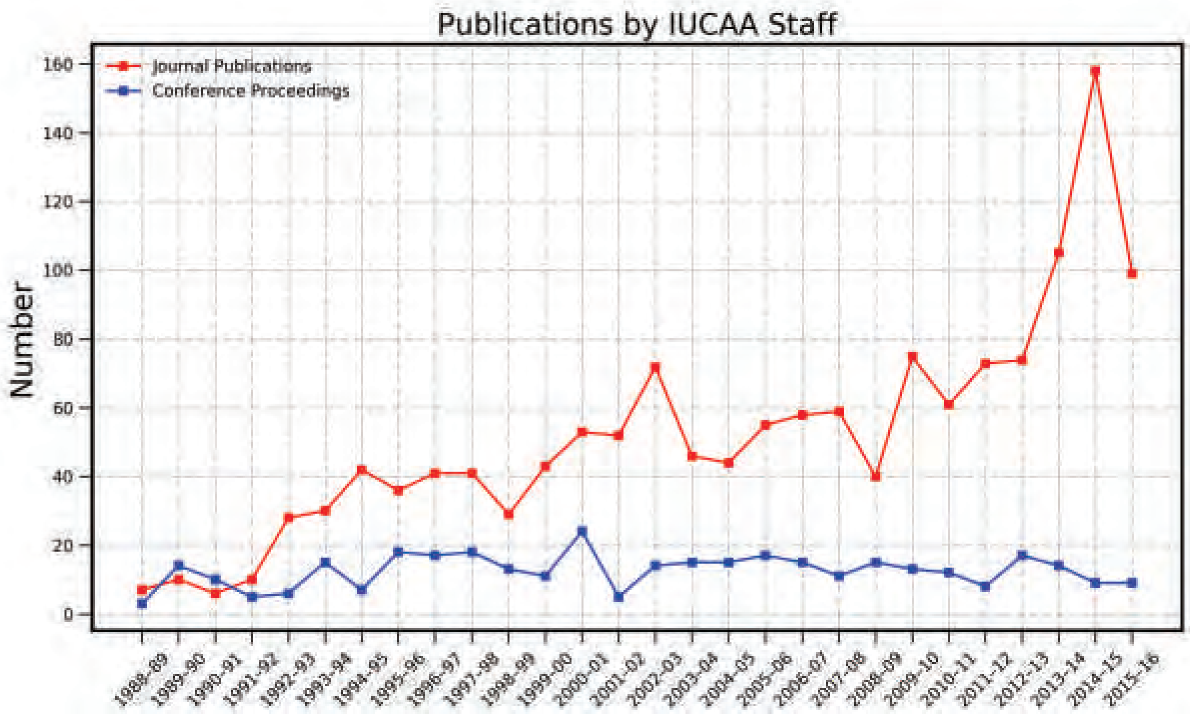
Bullet trainchya yugat (in Marathi) (*In the age of the bullet train*), Saptarang, Sakal, February 7, 2016.

The strange behaviour of gravity, The Asian Age, February 10, 2016.

Gurutvakarshanachya lahari (in Marathi) (*Gravitational waves*), Lokrang, Loksatta, February 21, 2016.
Shastradnyanchya vyatha (in Marathi) (*The problems of scientists*), Saptarang, Sakal, March 6, 2016.

Why science needs journalism, The Asian Age, March 16, 2016.

Should I return my Sahitya Akademi Award? (2016) Current Science, **110**, 1, 7.



PEDAGOGICAL

(A) IUCAA - NCRA GRADUATE SCHOOL LECTURES

Aseem Paranjape: Methods of Mathematical Physics I (14 lectures) (August - September 2015).

Kandaswamy Subramanian: Quantum and Statistical Mechanics I (14 lectures) (August - September 2015).

Dipankar Bhattacharya: Introduction to Astronomy and Astrophysics II (14 lectures) (October - December 2015).

Sukanta Bose: Quantum and Statistical Mechanics II (14 lectures) (October - December 2015).

Ranjeev Misra: Electrodynamics and Radiative Process II (14 lectures) (October - December 2015).

Sanjit Mitra: Methods of Mathematical Physics II (14 lectures) (October - December 2015).

T. Padmanabhan: Extragalactic Astronomy I (21 lectures) (January - February 2016).

A.N. Ramaprakash: Astronomical Techniques I (14 lectures) (January - February 2016).

Kanak Saha: Galaxies: Structure, Dynamics and Evolution I (21 lectures) (January - February 2016).

Gulab Dewangan: Extragalactic Astronomy II (14 lectures) (March - May 2016).

Neeraj Gupta: Interstellar Medium II (14 lectures) (March - May 2016).

(B) SAVITRIBAI PHULE PUNE UNIVERSITY, M.SC. (DEPARTMENTS OF PHYSICS AND SPACE SCIENCE) LECTURES

Durgesh Tripathi: Astronomy and Astrophysics I (August - September 2015).

R. Srianand: Astronomy and Astrophysics I (October - December 2015).

Varun Sahni: Astronomy and Astrophysics II (January - May 2016).

Ranjan Gupta: Laboratory Course (Theory 10 lectures), and related Observational Astronomy (10 laboratory and night experiments).

(C) SUPERVISION OF PH.D. THESES (DEGREE AWARDED)

Ajit K. Kembhai and **Ranjeev Misra**
Structure, Properties and Formation Histories of S0 Galaxies.
Student: Kaustubh Vaghmare (IUCAA).

T. Padmanabhan
Structure of Gravitational Theories with Focus on the Emergent Paradigm.
Student: Krishnamohan Parattu (IUCAA).

Tarun Souradeep
Challenges in Inferring New Physics from Cosmic Microwave Background Observations.
Student: Santanu Das (IUCAA).

R. Srianand
Probes of the Evolving Universe.
Student: Hamsa Padmanabhan (IUCAA).

Kandaswamy Subramanian
Magnetic Fields in the Universe: Understanding their Origin and Evolution.
Student: Pallavi Bhat (IUCAA).

(D) SUPERVISION OF PH.D. THESES (ONGOING)

Dipankar Bhattacharya

Accretion-induced evolution of neutron star magnetic field.
Student: Suman Bala (IUCAA).

Structure and stability of strongly magnetised compact stars.
Students: Prasanta Bera (IUCAA).

Indirect imaging in astronomy.
Student: Ajay Vibhute (Savitribai Phule Pune University).

Gulab Dewangan

X-ray emission from black hole X-ray binaries.
Student: Shah Alam (Jamia Millia Islamia, New Delhi, Co-guide).

Radio-loud AGN.
Student: Ritesh Ghosh (Visva Bharati University, Santiniketan, Co-guide).

On SED modelling and energy dependent variability.
Student: Labani Mallick (IUCAA).

Broad iron lines from neutron star low mass X-ray binary.
Stusent: Aditya Sow Mondal (Visva Bharati University, Santiniketan, Co-guide).

X-ray spectral variability of active galactic nuclei.
Student: Main Pal Rajan (IUCAA).

(E) SUPERVISION OF PROJECTS

Dipankar Bhattacharya

Nilankur Dutta (Savitribai Phule Pune University, M.Sc.) *Cyclotron resonance in neutron stars.*

Somdutta Ghosh (IIT, Madras, Chennai, VSP, IUCAA) *Mass radius relation of realistic white dwarfs.*

Hariram S. (BITS, Pilani) *Back projection technique for the CZT array of AstroSat.*

Faizan Ahmed Md. Humayun and Kalyan T. Choudhari (Savitribai Phule Pune University, M.Sc.*) Android portal for Virtual Observatory - India.*

Shrishti Sarogi, Dnyani Surkutwar and V. Mythri (MIT, Pune, B.E.) *Source reconstruction for AstroSat CZTI using side coded mask.*

Phalguni Shah (Science Academies' Summer Research Fellowship Programme) *Magnetic fields from turbulence.*

Gulab Dewangan

Savithri Ezhikkode (St. Thomas College, Kozhencherri, Ph.D.) *Broadband spectral investigation of active galactic nuclei.*

Mona Molham Mostafa (NRIAG, Helwan, Egypt) *X-ray spectral studies of Seyfert galaxies.*

Pramod Pawar (SRTM University, Nanded, Ph.D.) *Collaborative work on optical-X-ray variability of AGN.*

Bhavishya Poovanna (NIT, Surathkal, VSP, IUCAA) *X-ray spectral studies of Seyfert galaxies.*

Somak Raychaudhury

Tirna Deb (Presidency University, Kolkata, M.Sc.) *Estimation of total AGN feedback from clusters of galaxies.*

Rudrani Karchowdhury (Presidency University, Kolkata, Ph.D.) *The influence of environment on AGN activity.*

Tarun Souradeep

Lokahith Agasthya (IISER, Pune) *Introduction to scalar field inflation.*

Karthik Prabhu (IISER, Pune) *Bayesian estimation of statistical isotropy violation from CMB temperature field.*

Debajyoti Sarkar (IUCAA Graduate School) *Harmonic physics of cosmic microwave background.*

Kanak Saha

Atma Anand (IIST, Thiruvananthapuram, M.S.) *Orbits of a planet in a proto-planetary disk.*

Debatri Chattopadhyay (IIT, Kharagpur, VSP, IUCAA) *Orbits in a planar non-axisymmetric potential.*

Vishnu Sharma (BITS, Pilani) *Fourier transform on galaxy images.*

Duegesh Tripathi

Namrata Roy (Presidency University, Kolkata, M.Sc.) *Characteristics of chromospheric spectral line in solar flares.*

(F) SEMINARS, COLLOQUIA AND LECTURES

Varun Bhalerao

NuSTAR view of supergiant fast X-ray transients, Recent Trends in Compact Object Studies, RETCO - II, ARIES, May 7, 2015.

X-ray telescope, Refresher Course in Astronomy and Astrophysics (for College and University Teachers) and Vacation Students' Programme, IUCAA, May 15, 2015.

Transients, Refresher Course in Astronomy and Astrophysics (for College and University Teachers) and Vacation Students' Programme, IUCAA, May 22, 2015.

NuSTAR data analysis, Extragalactic Relativistic Jets: Cause and Effect, ICTS, Bengaluru, October 20, 2015.

Finding electromagnetic counterparts to transient gravitational wave sources, AEI - ICTS Workshop on Gravitational Waves, ICTS, Bengaluru, November 5, 2015.

Transients with CZTI, U.K. - India Educational Research Initiative Meeting on AstroSat, IUCAA, January 18, 2016.

Finding EM counterparts to GW sources, Indo - Korean Gravitational Wave Meeting, IUCAA, January 28, 2016.

AstroSat, New York University, Abu Dhabi, March 15, 2016.

Dipankar Bhattacharya

Calibration of scientific payloads aboard AstroSat, 10th Meeting of the International Astronomical Consortium for High Energy Calibration, Beijing, April 21, 2015.

Compact objects, Training Programme in Astronomy for African Scientists, IUCAA, April 27, 2015.

Cosmic explosions, Training Programme in Astronomy for African Scientists, IUCAA, April 28, 2015.

AstroSat, Workshop on Paving the Way for Multi-wavelength Astronomy, Lorentz Center, Leiden, The Netherlands, July 16, 2015.

The current X-ray astronomy scene in India, Beyond AstroSat Meeting, IIA, Bengaluru, July 28, 2015.

High energy emission from rotation powered pulsars, X-ray Astronomy Workshop, TIFR, Mumbai, August 13, 2015.

Introduction to radio astronomy, Radio Astronomy School, NCRA, Pune, August 31, 2015.

Science with AstroSat, Regional Meeting on Trends and Challenges in Astronomy and Astrophysics, Calcutta University, Kolkata, September 12, 2015.

AstroSat, Cloudy Workshop, IUCAA, September 25. 2015.

Introduction to X-ray astronomy, Mini-Workshop on AstroSat CZTI, IUCAA, November 5, 2015.

Coded mask imaging, Mini-Workshop on AstroSat CZTI, IUCAA, November 7, 2015.

Science with AstroSat, One-day Workshop on Space Astronomy, MIT, Pune, November 17, 2015.

Detectors in astronomy, IUCAA - NCRA Radio Astronomy Winter School, IUCAA, December 15, 2015.

AstroSat, IUCAA - NCRA Radio Astronomy Winter School, IUCAA, December 24, 2015.

AstroSat PV phase: Coordinated observations, 100 Days of AstroSat Operations, ISRO Satellite Centre, Bengaluru, January 5, 2016.

Cyclotron line science: Lessons from 4U0115+63, LAXPC Science Workshop, TIFR Balloon Facility, Hyderabad, January 12, 2016.

AstroSat and science of neutron stars, U.K. - India Educational Research Initiative Meeting on AstroSat, IUCAA, January 18, 2016.

Discussion on GRBs with AstroSat, International Conference on Jet Triggering Mechanisms in Black Hole Sources, TIFR, Mumbai, January 23, 2016.

The AstroSat mission, National Space Science Symposium, SPL, VSSC, Thiruvananthapuram, February 11, 2016.

AstroSat: Coordinated observations, 11th Meeting of the International Astronomical Consortium for High Energy Calibration, IUCAA, Pune, March 1, 2016.

AstroSat calibration update, 11th Meeting of the International Astronomical Consortium for High Energy Calibration, IUCAA, Pune, March 1, 2016.

Sukanta Bose

Low-latency data analysis and detector characterization challenges, Next Detectors in Gravitational Wave Astronomy, Kavli Institute for Astronomy and Astrophysics, Beijing, April 22, 2015.

Preparations for EM follow-up of GW observations in the Advanced LIGO era, American Physical Society Meeting (NW Section), Pullman, USA, May 15, 2015.

Neutron star equation of state from gravitational wave observations, Binary Neutron Star Workshop, Thessaloniki, May 29, 2015.

Effect of sine-Gaussian glitches in compact binary coalescence searches, Amaldi Meeting, Gwangju, South Korea, June 2015.

From GW detection challenges to GW astrophysics, Advances in Astroparticle Physics and Cosmology, SINP, Kolkata, October 14, 2015.

Gravitational waves and the neutron star equation of state, IIT, Kanpur, October 29, 2015.

Time-domain astronomy with gravitational waves?, Workshop on General Relativity at its Centennial, Jamia Millia Islamia, New Delhi, December 10, 2015.

Constraining the neutron star equation of state with gravitational wave observations, Institute for Nuclear Theory, Seattle, USA, February 19, 2016.

The observation of a gravitational wave signal and the new opportunities it opens up, IISER, Kolkata, March 5, 2016.

The observation of a gravitational wave signal and the new opportunities it opens up, SINP, Kolkata, March 7, 2016.

Sumanta Chakraborty

A quantum peek inside the black hole event horizon, IACS, Kolkata, April 21, 2015.

Extra dimension with radion and torsion, IACS, Kolkata, July 30, 2015.

From spacetime geometry to thermodynamics, IIT, Gandhinagar, September 2, 2015.

Principle of least action in general relativity, Physical Research Laboratory, Ahmedabad, September 3, 2015.

Action principle in general relativity, IACS, Kolkata, October 5, 2015.

The dynamical evolution of the spacetime, SNBCBS, Kolkata, October 7, 2015.

Action principle for general relativity and its relation to null surfaces, Indian Statistical Institute, Kolkata, October 8, 2015.

Thermodynamic interpretation of geometrical variables associated with null surfaces, Advances in Astroparticle Physics and Cosmology, SINP, Kolkata, October 12 - 17, 2015.

The dynamical evolution of the spacetime and equipartition, Institute of Mathematical Sciences, Chennai, November 4, 2015.

General relativity and principle of least action, IIT, Madras, Chennai, November 5, 2015.

Thermodynamics of null surfaces, International Conference on Gravitation and Cosmology, IISER, Mohali, December 14, 2015.

Discrete quantum spectrum of black holes, International Conference on Gravitation and Cosmology, IISER, Mohali, December 17, 2015.

From spacetime geometry to thermodynamics, Presidency University, Kolkata, March 16, 2016.

Gravity and thermodynamics: The importance of being null, SINP, Kolkata, March 17, 2016.

Naresh Dadhich

On pure Lovelock gravity, Albert Einstein Institute, Golm, Germany, June 10, 2015.

On pure Lovelock gravity, University of Oldenburg, Germany, June 16, 2015.

Magnetic Penrose process, Goethe University, Frankfurt, Germany, June 26, 2015.

On pure Lovelock gravity, University of Santiago de Compostela, Spain, June 29, 2015.

On spacetime structure, University of Amsterdam, The Netherlands.

Pure Lovelock Kasner metrics, 14th Marcel Grossmann Meeting, University of Rome "La Sapienza", Rome, July 12 - 18, 2015.

Gravity in higher dimensions, 14th Marcel Grossmann Meeting, University of Rome "La Sapienza", Rome, July 12 - 18, 2015.

Cosmological constant: A constant of spacetime structure, 14th Marcel Grossmann Meeting, University of Rome "La Sapienza", Rome, July 12 - 18, 2015.

Emergence of constant curvature spacetime in the loop quantum evolution of black hole interiors, 14th Marcel Grossmann Meeting, University of Rome "La Sapienza", Rome, July 12 - 18, 2015.

Gravity in higher dimensions, South African Gravitational Society Meeting, Rhodes University, Grahams Town, South Africa, September 1, 2015.

Indian contributions to GR: A centennial review, International Conference on Gravitation and Cosmology, IISER, Mohali, December 14 - 18, 2015.

Some gravitational features as guiding principle for gravitational equation in higher dimensions, Workshop on Field Theoretic Aspects of Gravity - XI, SNBNCBS, Kolkata, February 23, 2016.

Relativity for everyone, Bajali College, Pathsala, Assam, March 14, 2016.

Relativity for everyone, Cotton College, Guwahati, March 15, 2016.

Indian contributions to GR: A centennial review, Cotton College, Guwahati, March 15, 2016.

Gravity in higher dimensions, Physics Department, Gauhati University, Guwahati, March 16, 2016.

Relativity for everyone, Dibrugarh University, March 17, 2016.

Indian contributions to GR: A centennial review, Dibrugarh University, March 18, 2016.

Sanjeev Dhurandhar

The cross-correlation search for periodic sources of gravitational waves, Cornell University, Ithaca, July 9, 2015.

Effect of sine-Gaussian glitches on compact coalescing binary searches, Syracuse University, New York, August 14, 2015.

The cross-correlation search for periodic sources of gravitational waves, University of Texas, Rio Grands Valley, August 21, 2015.

Astronomy of the 21st century: Gravitational wave astronomy, IISER, Bhopal, October 30, 2015.

Einstein's centennial gift: Gravitational waves discovered, IISc, Bengaluru, February 19, 2016.

Einstein's centennial gift: Gravitational waves discovered, CEBS, Mumbai University, March 15, 2016.

Einstein's centennial gift: Gravitational waves discovered, IISER, Thiruvananthapuram, March 21, 2016.

Einstein's centennial gift: Gravitational waves discovered, IIT, Kanpur, March 31, 2016.

Girjesh Gupta

Study of sunspot waves and oscillations with SUIT/Aditya, SUIT Science Meeting, Udaipur Solar Observatory, December 16 - 17, 2015.

MHD waves in the solar atmosphere, IIT, Delhi, New Delhi, January 21, 2016.

Spectroscopic evidence of temperature dependent damping of Alfven waves in the off-limb solar corona, Dynamic Sun I, IIT - BHU, Varanasi, February 22 - 26, 2016.

Observations of propagation and damping of waves in the solar atmosphere, IUCAA, March 23, 2016.

Role of waves and small-scale transients in the heating of solar atmosphere, IISER, Pune, March 30, 2016.

Neeraj Gupta

Galaxy evolution through absorption lines, IISER, Pune, April 9, 2015.
The MeerKAT Absorption Line Survey (Via video; SALT Science Meeting), Cape Town, South Africa, June 3, 2015.

Galaxy evolution using SKA pathfinders, Conference on Cosmology using HI, RRI, Bengaluru, June 26, 2015.

HI in the galaxy and beyond, IUCAA - NCRA Radio Astronomy Winter School, IUCAA, December 18, 2015.

Ranjan Gupta

Modelling of interstellar dust and its comparison to observational data, Texas A and M University, College Station, USA, June 17, 2015.

An overview of automated classification schemes applied to astronomy, Advance Workshop on Time Domain Astronomy and Cosmology, CMS. College, Kottayam, July 9 - 11, 2015.

Light scattering tools and their comparative approach for understanding astrophysical phenomena, Regional Meeting on Trends and Challenges in Astronomy and Astrophysics, University of Calcutta, Kolkata, September 10 - 12, 2015.

Introduction to astronomical spectroscopy, Indo-French School on Optical Spectroscopy, IUCAA, November 23 - 28, 2015.

India's involvement in Mega Projects in physics and astronomy, SUNY Oswego, USA, December 16, 2015.

Light scattering tools and their comparative approach for understanding astrophysical phenomena, Workshop on Electromagnetic Light Scattering as a Tool in Astronomy and Astrophysics, M.K. Bhavnagar University, January 4 - 5, 2016.

Career opportunity in astronomy and *India's involvement in Mega Projects,* National Colloquium on Research and Career Opportunities in Astronomy and Astrophysics, Bharatiya Vidya Bhavan's Sheth R.A. College of Science, Ahmedabad, January 4, 2016.

Ajit K. Kembhavi

Application of data techniques cross domains: Some insights, Indian National Science Academy, New Delhi, November 5, 2015.

Introduction to astronomy and astrophysics, Training Programme in Astronomy for African Scientists, IUCAA, April 20 - May 1, 2015.

Ranjeev Misra

Black holes in the Universe, Lucknow University, May 2015.

AstroSat: X-ray binaries, AstroSat Mini-Workshop, Southampton, U.K., June 2015.

X-ray variability, Advanced Workshop on Time Domain Astronomy and Cosmology, CMS College, Kottayam, July 9 - 11, 2015.

AstroSat: X-ray binaries, AstroSat LAXPC Science, TIFR, Mumbai, August 2015.

X-ray variability, Regional Meeting on Trends and Challenges in Astronomy and Astrophysics, University of Calcutta, Kolkata, September 10 - 12, 2015.

Black holes in the Universe, Assam Don Bosco University, Guwahati, October 2015.

AstroSat, North-East Meet of Astronomers, Tezpur University, October 26 - 28, 2015.

Black holes in the Universe, Government College, Chittur, November 2015.

AstroSat, Workshop on Multi-wavelength Astronomy, Providence Women's College, Kozhikode, November 25 - 27, 2015.

Accretion processes, Workshop on Novae and Accreting Binaries: A Multi-wavelength Study, CEBS, Mumbai University, December 2 - 6, 2015.

AstroSat: X-ray binaries, AstroSat LAXC Science, TIFR, Hyderabad, January 2016.

AstroSat, Workshop on Astronomical Data Analysis, Assam Don Bosco University, Guwahati, March 2016.

AstroSat, Workshop on Astronomical Data Analysis, J. B. College, Jorhat, March 2016.

Sanjit Mitra

Gravitational wave astronomy: Opening new windows to the Universe, IIT, Bombay, Mumbai, October 15, 2015.

Jayant V. Narlikar

Three pillars of wisdom: Physics, mathematics and astronomy, Mumbai University, April 7, 2015.

How well do we know our universe?, Refresher Course in Astronomy and Astrophysics (for College/University Teachers) and Vacation Students' Programme, IUCAA, June 5, 2015.

The early development of general relativity in India, International Conference to Celebrate 100 Years of Einstein's General Relativity and Birth Centenary Year of Professor Sir Fred Hoyle, Charotar University of Science and Technology, Anand, June 21, 2015.

Action at a distance in curve spacetime, International Conference to Celebrate 100 Years of Einstein's General Relativity and Birth Centenary Year of Professor Sir Fred Hoyle, Charotar University of Science and Technology, Anand, June 23, 2015.

Early work on general relativity in India, North Bengal University, Siliguri, August 18, 2015.

Analytical thinking, Presidency University, Kolkata, August 22, 2015.

Searches for microorganisms in the Earth's atmosphere, Natural Sciences Society, Fitzwilliam College, Cambridge, U.K., October 7, 2015.

Fred Hoyle's manifold contributions: A personal view, Institute of Astronomy, Cambridge, U.K., October 8, 2015.

Fred theories and ideas about gravity, Royal Astronomical Society's Specialist Meeting to Celebrate the 100th Anniversary of Fred Hoyle, U.K., October 9, 2015.

Some outstanding issues in astronomy, Dibrugarh University, November 2, 2015.

Some outstanding issues in astronomy, SRTM University, Nanded, December 9, 2015.

Some outstanding issues in cosmology, IIT, Bombay, Mumbai, December 27, 2015.

Are we alone?, Cochin University of Science and Technology, Kochi, February 11, 2016.

T. Padmanabhan

Gravity and the cosmos, CEBS, Mumbai University, April 17, 2015.

Cosmology: Status and prospects, Goyal Award Lecture, University of Kurukshetra, August 27, 2015.

Distribution function of the atoms of spacetime and the nature of gravity, 35th Max Born Symposium, The Planck Scale II, Wrocklaw University, Poland, September 7, 2015.

Gravity and the cosmos, Frankfurt Institute for Advanced Studies, Frankfurt am Main, September 14, 2015.

Kinetic theory of atoms of space - aka gravity, TIFR, Mumbai, October 5, 2015.

Atoms of spacetime and the nature of gravity (Keynote Address), Third International Symposium on Quantum Mechanics (EMQM15), Vienna, October 25, 2015.

The curious cosmos: Are we missing the message?, IAP, Paris, October 27, 2015.

Atoms of spacetime, IAP, Paris, October 30, 2015.

Gravity and/of cosmos, Indian Academy of Sciences, Annual Meeting, Symposium on General Relativity, IISER, Pune, November 7, 2015.

Gravity and the cosmos, 14th S. Datta Majumdar Memorial Lecture, IIT, Kharagpur, November 16, 2015.

Atoms of space and the nature of gravity, IIT, Kharagpur, November 17, 2015.

Kinetic theory of atoms of space - aka gravity, A.K. Raychaudhuri Memorial Lecture, IACS, Kolkata, November 18, 2015.

Action principle in general relativity, IRC, North Bengal University, Siliguri, November 23, 2015.

First hundred years of GR: Successes, status and prospects, The 28th Texas Symposia on Relativistic Astrophysics, December 14, 2015.

Emergent gravity paradigm: Recent progress, IISER, Mohali, December 17, 2015.

Cosmic odyssey: Past present and future, The C. D. Deshmukh Memorial Lecture, India International Centre, Delhi, January 14, 2016.

Somak Raychaudhury

Searching for the missing baryons, Regional Meeting on *Trends and Challenges in Astronomy and Astrophysics,* University of Calcutta, Kolkata, September 10 - 12, 2015.

The algebra-geometry duality (with Mahan Mj, TIFR, Mumbai), *Quantum Physics and Madhyamika Philosophical View,* Jawaharlal Nehru University, New Delhi, November 12 - 13, 2015.

Optical spectroscopy of galaxies, Indo-French School for Optical Spectroscopy, IUCAA, November 23 - 28, 2015.

Finding black holes, Nurture Camp for Indian Astronomy Olympiad Finalists, Hyderabad, December 14, 2015.

The internal and external kinematics of the Local Group, International Conference of Celestial Mechanics and Dynamical Astronomy, Maulana Azad National Urdu University, Hyderabad, December 15 - 17, 2015.

Radio galaxies in groups and clusters: Effect of local environment, International Conference on Jet Triggering Mechanisms in Black Hole Sources, TIFR, Mumbai, January 20 - 23, 2016.

The early evolution of galaxies in small groups, School and Workshop on Large Scale Structure: From Galaxies to the Cosmic Web, IUCAA, February 9, 2016.

Why we need to go to space to see the sky (Keynote Address), Astronautical Society of India Annual Meeting, Space Applications Centre, Ahmedabad, February 25, 2016.

Tarun Souradeep

Cosmos-e-Planck, TIFR, Mumbai, April 29, 2015.
LIGO - India, Cosmic Dawn Workshop, University of Maryland, USA, May 8, 2015.

Astronomy and astrophysics, Presentation to Prime Minister of India, New Delhi, August 19, 2015.

LIGO - India: A launch pad for gravitational wave astronomy, Calcutta University, Kolkata, September 10 - 12, 2015.

Cosmology scripted in a pristine cosmic glow, National Defence Academy, Pune, September 18, 2015.
Sampling ensemble of Universe, First State of the Universe Seminar, TIFR, Mumbai, September 28, 2015.

Agnostic approach to cosmology, TIFR, Mumbai, September 29, 2015.

Agnostic cosmology with Planck CMB measurements, Symposium on Black Holes and Cosmology, IIT, Madras, Chennai, October 6, 2015.

Cosmology in the post Planck era, AAPCOS - 2015, SINP, Kolkata, October 12 - 17, 2015.

Post Planck era of cosmology, IISER, Bhopal, October 16, 2015.

Post Planck cosmology, CICAHEP - 2015, Dibrugarh University, November 2 - 5, 2015.

LIGO - India: A launch pad for gravitational wave astronomy, SRTM University, Nanded, December 9, 2015.

Contemporary approach in cosmology, General Relativity Centennial, CTP, Jamia Millia Islamia, New Delhi, December 11, 2015.

Post-Planck cosmos, General Relativity Centennial, CTP, Jamia Millia Islamia, New Delhi, December 11, 2015.

Bayesian analysis on the sphere beyond statistical isotropy, 9th International Triennial Symposium on Probability and Statistics, Kolkata, December 30, 2015.

Planck's cosmos, NCRA, Pune, June 5, 2015.

LIGO - India readiness at the discovery of gravitational waves, The Universe in a New Light, ICTS, Bengaluru, February 13, 2016.

LIGO - India, LIGO - Virgo Collaboration Meeting, Pasadena, USA, March 16, 2016.

Indian refinement to gravitational wave discoveries, HRI, Allahabad, March 21, 2016.

Beyond gravitational wave discoveries with LIGO - India, Sri Venkateswara College, New Delhi, March 31, 2016.

R. Srianand

Outflows from QSOs, extragalactic relativistic jets: Cause and effect, ICTS, Bengaluru, October, 2015.

Star formation in high-z galaxies, School and Workshop on Large Scale Structure: From Galaxies to the Cosmic Web, IUCAA, February 1 - 12, 2016.

Probing the universe with QSO absorption lines, IIT, Madras, Chennai, February 2016.
Fundamental physics and cosmology with QSO absorption lines, TIFR, Mumbai, January 2016.

(G) LECTURE COURSES

Dipankar Bhattacharya

Introduction to astronomy and stars (4 lectures) Refresher Course in Astronomy and Astrophysics (for College/University Teachers) and Vacation Students' Programme, IUCAA, May 5 - 8, 2015.

Neutron stars: Physics of the magnetic field (4 lectures) Neutron Stars: A Pathfinder Workshop, NCRA, Pune, January 6 - 13, 2016.

Sanjeev Dhurandhar

Gravitational waves (4 lectures) Winter School on General Relativity and its Applications, IRC, North Bengal University, Siliguri, November 23 - 28, 2015.

General relativity and gravitational waves (4 lectures) National School of Gravitational Waves, IRC, CUSAT, Kochi, December 28 - January 1, 2016.

General relativity (3 lectures) CUHP, Dharamshala, March 2 - 5, 2016.

Neeraj Gupta

Interstellar medium and radio astronomy (4 lectures) Refresher Course in Astronomy and Astrophysics (for College and University Teachers) and Vacation Students' Programme, IUCAA, May 4 - June 5, 2015.

Ranjan Gupta

Stellar spectroscopy and instrumentation (2 lectures), Refresher Course in Astronomy and Astrophysics (for College/University Teachers) and Vacation Students' Programme, IUCAA, May 4 - June 5, 2015.

Basics of astronomy (4 lectures), Advance Meteorological Training, IMD - CTI, Pune, January 11 - 13, 2016.

Ajit K. Kembhavi

Stellar structure (3 lectures) Training Programme in Astronomy for African Scientists, IUCAA, April 20 - May 1, 2015.

Galaxies (3 lectures) Refresher Course in Astronomy and Astrophysics (for College/University Teachers) Vacation Students' Programme, IUCAA, May 4 - June 5, 2015.

Sanjit Mitra

Gravitational waves data analysis (2 lectures), School on Neutron Stars, NCRA, Pune, January 13, 2016.

Gravitational waves theory (2 lectures) and *GW data analysis* (2 hands-on sessions), School on Gravitation and Astroparticle Physics, CUHP, Dharamshala, March 4 - 5, 2016.

Ranjeev Misra

Radiative processes (3 lectures) Refresher Course in Astronomy and Astrophysics (for College/University Teachers) and Vacation Students' Programme, IUCAA, June 2015.

Jayant V. Narlikar

Cosmology (10 lectures) CEBS, Mumbai University, March 30 - April 10, 2015.

Aseem Paranjape

Large scale structure and the excursion set approach (3 lectures) IISER, Mohali, March 9 - 11, 2016.

T. Padmanabhan

Special and general relativity (2 lectures) Training Programme in Astronomy for African Scientists, IUCAA, April 20 - 21, 2015.

Special and general relativity (4 lectures), Refresher Course in Astronomy and Astrophysics (for College/ University Teachers) and Vacation Students' Programme, IUCAA, May 4 - June 5, 2015.

Newtonian gravity (2 lectures), SNBNCBS, Kolkata, November 16, 2015.

Statistical mechanics of gravitating system, *Electrostatics in weak gravitational field*, *Action principle for general relativity*, and *The atoms of space and the nature of gravity* (4 lectures), SNBNCBS, Kolkata, November 18 - 20, 2015.

Somak Raychuadhury

Space, time and the Universe (12 lectures) GenEd Course, Presidency University, Kolkata, September - November 2015.

Kanak Saha

Galaxy dynamics and evolution (4 lectures) Refresher Course in Astronomy and Astrophysics (for College/ University Teachers) and Vacation Students' Programme, IUCAA, May 4 - June 5, 2015.

Tarun Souradeep

Cosmology and early universe (2 lectures), Training Programme in Astronomy for African Scientists, IUCAA, April 20, 2015.

R. Srianand

GNs and IGM (4 lectures) Refresher Course in Astronomy and Astrophysics (for College/University Teachers) and Vacation Students' Programme, IUCAA, May 4 - June 5, 2015.

Introduction to optical spectroscopy (4 lectures) Indo - French School on Optical Spectroscopy, IUCAA, November 23 - 28, 2015.

Astronomical radiative transport (3 lectures) IUCAA - NCRA Radio Astronomy Winter School, IUCAA, December 15 - 24, 2015.

Kandaswamy Subramnaian

Fluids and magnetism (4 lectures) Refresher Course in Astronomy and Astrophysics (for College/University Teachers) and Vacation Students' Programme, IUCAA, May 4 - June 5, 2015.

(H) POPULAR/PUBLIC LECTURES

Varun Bhalerao

Careers in astronomy, Jyotirvidya Parisanstha, Pune, May 17, 2015.

Distance ladder in astronomy, Indian National Astronomy Olympiad Selection-cum-Training Camp, HBCSE, Mumbai, June 1, 2015.

Building a cutting-edge space telescope, ISRO Workshop, MIT, Pune, November 17, 2015.

Contemporary Indian astronomy, New English School, Pune, December 5, 2015.

Dipankar Bhattacharya

AstroSat, Fergusson College, Pune, September 14, 2015.

AstroSat, National Science Day, IUCAA, February 28, 2016.

Sanjeev Dhurandhar

Einstein's centennial gift: Gravitational waves discovered, Celebrating the Discovery of Gravitational Waves, IUCAA, February 12, 2016.

Einstein's centennial gift: Gravitational waves discovered, National Science Day, IUCAA, February 28, 2016.

Einstein's centennial gift: Gravitational waves discovered, DRDO, Pune, February 29, 2016.

Einstein's centennial gift: Gravitational waves discovered, CUHP, Dharamshala, March 3, 2016.

Einstein's centennial gift: Gravitational waves discovered (with Sanjit Mitra), Vishwakarma Institute of Technology, Pune, March 11, 2016.

Einstein's centennial gift: Gravitational waves discovered, Marathi Vidnyan Parishad and Yashawantrao Chavan Pratishthan, Y. B. Chavan Sabhagruha, Mumbai, March 14, 2016.

Einstein's centennial gift: Gravitational waves discovered, IIST, Thiruvananthapuram, March 19, 2016.

Einstein's centennial gift: Gravitational waves discovered, IIT, Kanpur, March 30, 2016.

Ajit K. Kembhavi

Mega Projects for Indiana astronomy and the formation of centicular galaxies, Department of Applied Mathematics, Calcutta University, Kolkata, September 11, 2015.

Mega Projects for Indian astronomy and the formation of centicular galaxies, Department of Statistics, Calcutta University, Kolkata, September 12, 2015.

Space: In three and four dimensions, Sinhagad College of Architecture, Pune, February 15, 2016.

Sanjit Mitra

Gravitational wave astronomy: Opening new windows to the Universe, 2nd Saturday Lecture and Demonstration Programme, IUCAA, February 13, 2016.

Gravitational waves: Dawn of a new era!, Antariksh Club, Vishwakarma Institute of Technology, Pune, March 10, 2016.

Jayant V. Narlikar

Anomalous redshifts, Vidyalankar Institute of Technology, Mumbai, April 2, 2015.

Vishwat aapan ekate aahot ka? (in Marathi) (Are we alone in the universe?), BARC, Mumbai, April 6, 2015.

Cosmology, *Fred Hoyle and I*, Nehru Centre, Mumbai, April 9, 2015.

Why I do not subscribe to the big bang?, Institute of Chemical Technology, Mumbai, April 10, 2015.

Search for extra-terrestrial life, Training Programme in Astronomy for African Scientists, IUCAA, April 22, 2015.

Fascinating views in the solar system, Ishan Vikas Programme, IISER, Pune, May 27, 2015.

Cosmic illusions, 2nd Saturday Lecture and Demonstration Programme, IUCAA, July 11, 2015.

Disate tase nasate ... kadhi kadhi (in Marathi) (Cosmic illusions), 2nd Saturday Lecture and Demonstration Programme, IUCAA, July 11, 2015.

Vyapak sapekshata: 100 varshanantar (in Marathi) (General relativity: After 100 years), Astronomica Club, N.M.V. Girl's High School, Pune, July 17, 2015.

Searches for life in our Universe, North Bengal University, Siliguri, August 19, 2015.

How well do we know our Universe?, Presidency University, Kolkata, August 21, 2015.

Convocation Address, RTM Nagpur University, August 29, 2015.

Searches for extraterrestrial life: An Indian experiment, University of Petroleum and Energy Studies, Dehradun, September 5, 2015.

The challenges and rewards of creating and managing a scientific institution, 3rd Foundation Day Lecture, NIBM, Pune, September 24, 2015.

Prithvipalikadil jeevshrusticha shodh (in Marathi) (Searches for life outside the Earth), Janta Shikshan Sanstha's Kisan Veer Mahavidyalaya, Wai, October 20, 2015.

Vishwat aapan ekatech aahot ka? (in Marathi) (Are we alone in the universe?), SRTM University, Nanded, December 8, 2015.

Me vaidnyanik kasa zalo? (in Marathi) (How I became a scientist?), Dnyanprabodhini, Fergusson College, Pune, January 13, 2016.

Are we alone?, CMS College, Kottayam, February 8, 2016.

Are we alone?, Nirmala College, Muvattupuzha, February 9, 2016.

Are we alone?, Rajagiri School, Kalamassery, February 10, 2016.

Searches for life outside the Earth, Kolhapur Institute of Technology's College of Engineering, March 6, 2016.

T. Padmanabhan

Gravity an emergent phenomenon, Charotar University of Science and Technology, Anand, June 22, 2015.

The enigma of gravity, BD College of Engineering, Sevagram, Wardha, July 13, 2015.

Cosmology: Status and prospectus, Solapur Science Centre, August 31, 2015.

Gravity and the cosmos, IRC, North Bengal University, Siliguri, November 26, 2015.

Nature of gravity, TKM College of Arts and Science, Kollam, February 8, 2016.

Universe: Its history and mysteries, National Space Science Symposium, VSSC, Thiruvananthapuram, February 9, 2016.

Somak Raychaudhury

Future of astronomy research in India, Meet the Scientists, West Bengal State Level Students Youth Science Fair, Kolkata, October 3, 2015.

How to find black holes?, Ballygunge Government High School, Kolkata, March 16, 2016.

Tarun Souradeep

LIGO - India: Beyond the discovery of gravitational waves, National Camp, Physics Olympiad, HBCSE, Mumbai, June 6, 2016.

Durgesh Tripathi

Solar astronomy in India, Science Popularisation Workshop for Teachers and School Students, IUCAA, MVS, November 28, 2015.

Journey of a photon from Sun to Earth, 2^{nd} Saturday Lecture and Demonstration Programme, IUCAA, April 11, 2015.

(I) RADIO/TV PROGRAMMES

Sanjeev Dhurandhar

Discovery of gravitational waves (with Varun Bhalerao and Ajit Kembhavi) All India Radio, Pune, February 14, 2016.

TV interviews: On 6 different channels: Rajya Sabha, Sam, NDTV, etc. February 2016.

Jayant V. Narlikar

Moon to mars: A Space Odyssey (Part I), All India Radio, July 15, 2015.

Moon to mars: A Space Odyssey (Part I), All India Radio, July 22, 2015.

Vaartaavali (in Sanskrit), DD News, August 29, 2015.

Ek videshi bhuja (in Hindi), Vidnyan Bharati, All India Radio, October 28, 2015.

Recent development in the field of gravitational waves (in Hindi), All India Radio, March 23, 2016.

Tarun Souradeep

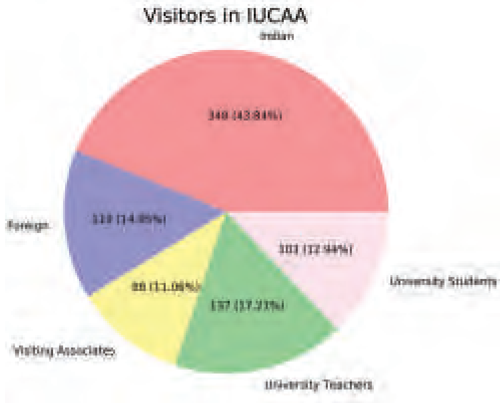
Eureka, Rajya Sabha TV, March 28, 2016.

SCIENTIFIC MEETINGS AND OTHER EVENTS

VACATION STUDENTS' PROGRAMME (VSP)

The Vacation Students' Programme (VSP) was held during May-July 2015. The VSP was coordinated by R. Srianand [For details see Khagol, No.103, July 2015]

REFRESHER COURSE IN ASTRONOMY AND ASTROPHYSICS

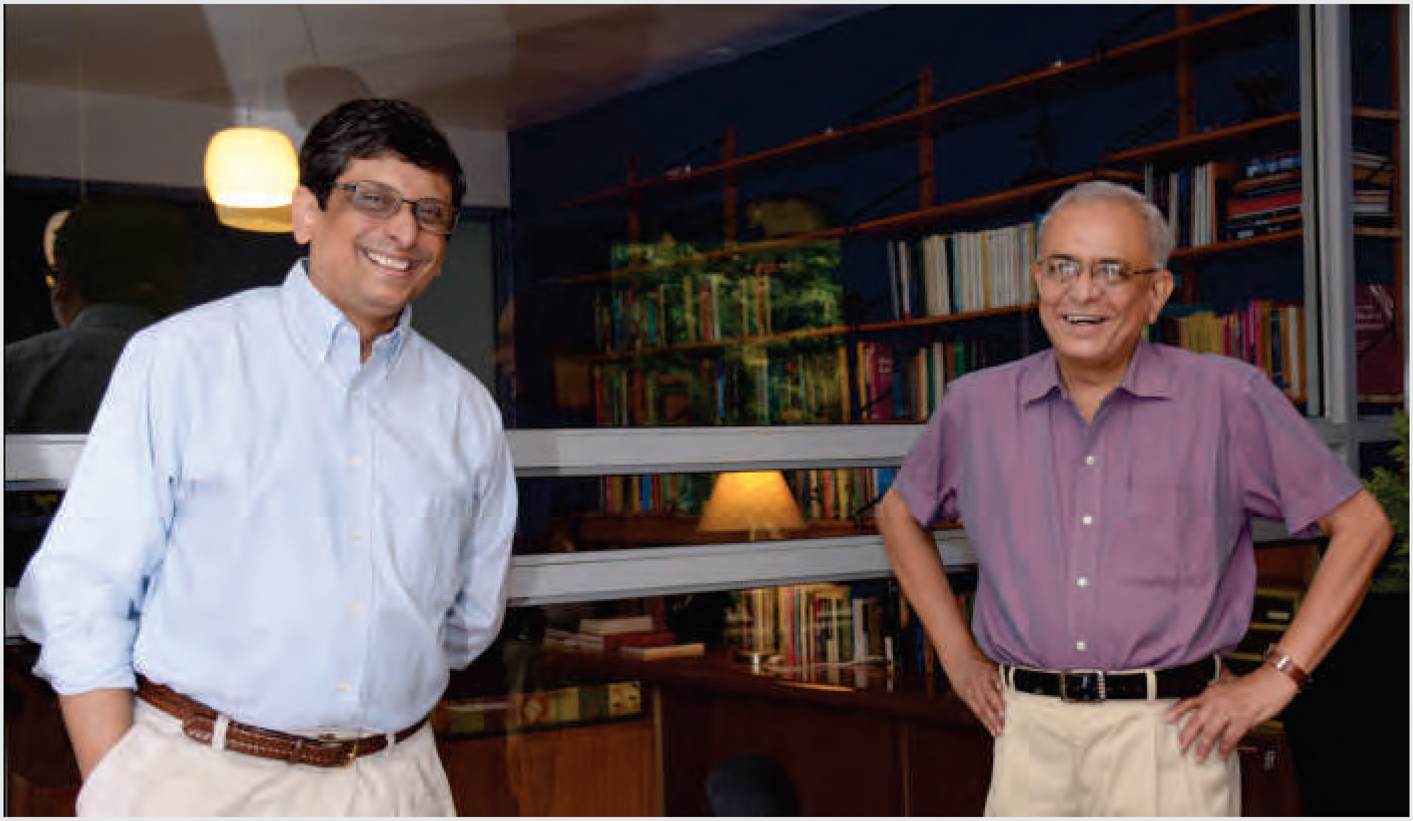


The biennial Refresher Course in Astronomy and Astrophysics for college and university teachers was held during May 4 - June 5, 2015. The refresher course was coordinated by Aseem Paranjape.
[For details see Khagol, No.103, July 2015]

TRAINING PROGRAMME IN ASTRONOMY FOR AFRICAN SCIENTISTS

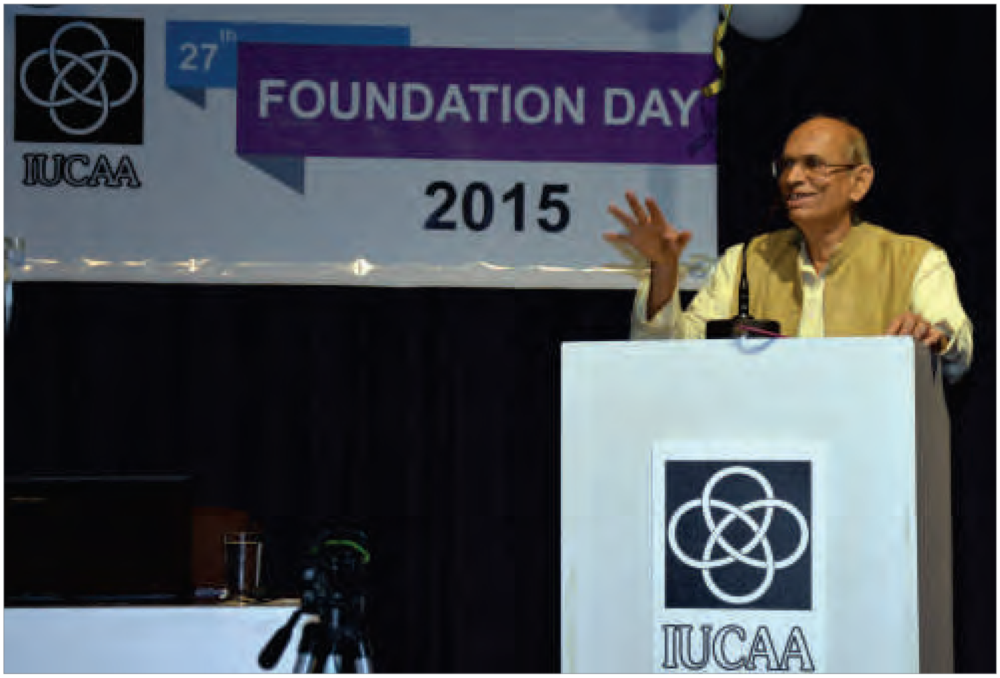
A Training Programme in Astronomy for African Scientists was sponsored by the Ministry of External Affairs and Department of Science and Technology, Government of India and was hosted by the IUCAA during April 20 - May 1, 2015.
[For details see Khagol, No.103, July 2015]

HONOURING A. K. KEMBHAVI'S SERVICE ON SUPERANNUATION



For details see Khagol, No.104, October 2015

27th FOUNDATION DAY LECTURE

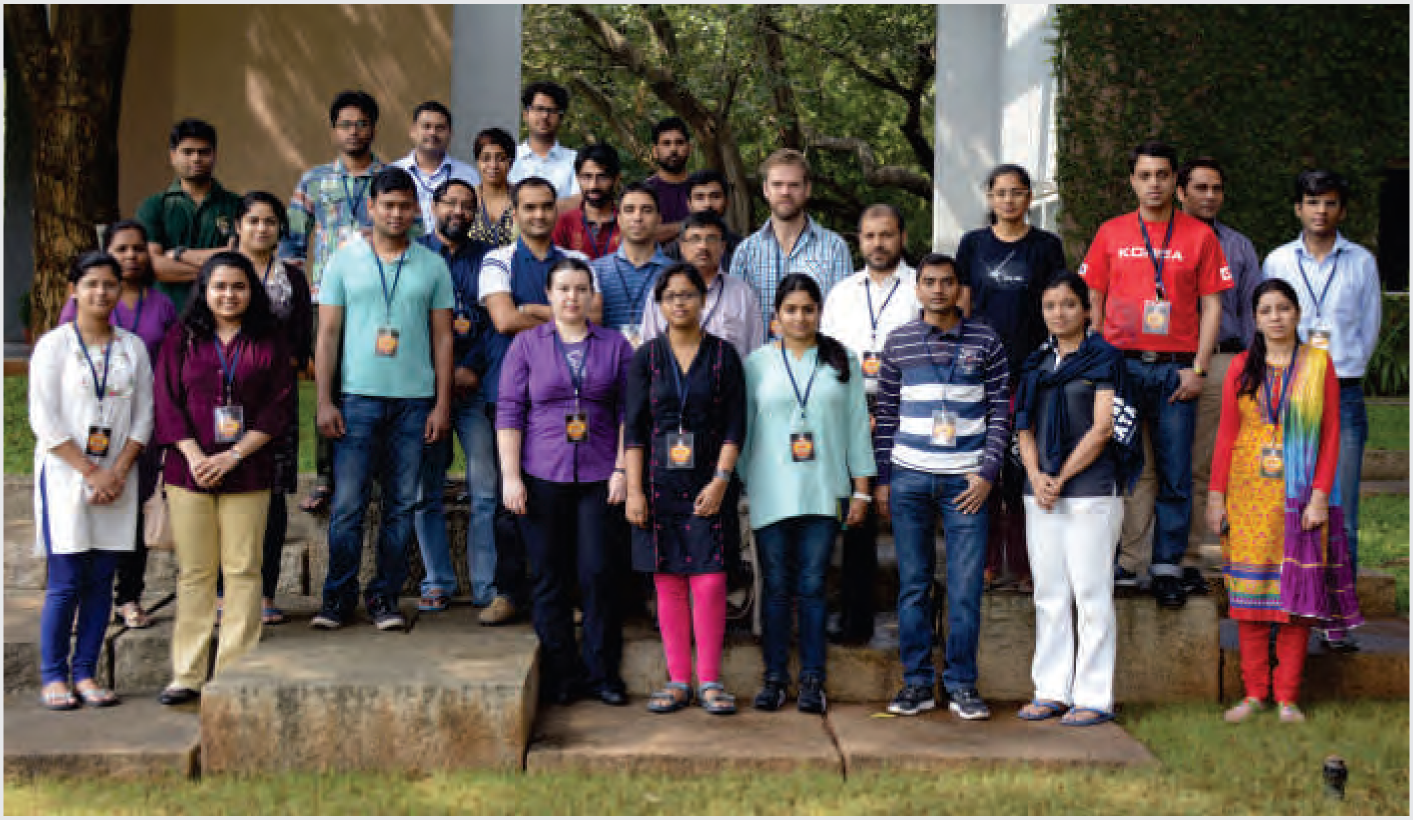


The 27th IUCAA Foundation Day Lecture, titled "A Natural History of Knowledge" was delivered by the eminent Indian ecologist, Professor Madhav Gadgil on December 29, 2015 in the Chandrasekhar Auditorium.
[For details see Khagol, No.105, January 2016]

CLOUDY WORKSHOP

Cloudy Workshop was conducted at IUCAA during September 21 - 26, 2015.
[For details see Khagol, No.105, January 2016]

INTERFACE REGION IMAGING SPECTROMETER (IRIS) DATA ANALYSIS WORKSHOP



An IRIS data analysis workshop, aimed at Ph.D. students and post-doctoral fellows was conducted at IUCAA during October 26 - 29, 2015. The workshop was coordinated by Durgesh Tripathi and Girjesh Gupta along with the local organising committee. [For details see Khagol, No.105, January 2016]

INDO - FRENCH ASTRONOMY SCHOOL FOR OPTICAL SPECTROSCOPY (IFSC 2015)

IUCAA and the Lyon Institute of Origins (LIO, Observatoire de Lyon, France) organised an Indo-French Astronomy School for Optical Spectroscopy (IFSC 2015) at IUCAA, during November 23 - 28, 2015. This workshop was coordinated by Ranjan Gupta, Philippe Prugniel and Mamta Pommier.
[For details see Khagol, No.105, January 2016]

IUCAA - NCRA RADIO ASTRONOMY WINTER SCHOOL

Radio Astronomy Winter School (RAWS) was organised jointly by IUCAA and NCRA during the December 15 - 24, 2015. The school was coordinated by Neeraj Gupta and Subhashis Roy from NCRA.
[For details see Khagol, No.105, January 2016]

CELEBRATING THE DISCOVERY OF GRAVITATIONAL WAVES


IUCAA

SCHOOL AND WORKSHOP ON LARGE SCALE STRUCTURE: FROM GALAXIES TO THE COSMIC WEB

The School and Workshop on Large Scale Structure: From Galaxies to the Cosmic Web for graduate students was conducted during February 1-12, 2016, coordinated by Aseem Paranjape.
[For details see Khagol, No.106, April 2016]

WORKSHOP ON BEST PRACTICES IN ASTRO-STATISTICS

Workshop on Best Practices in Astro-Statistics was held at IUCAA during January 28-30, 2016. Workshop was coordinated by Ranjan Gupta and H.P.Singh from University of Delhi.
[For details see Khagol, No.106, April 2016]

MEETING OF INTERNATIONAL ASTRONOMICAL CONSORTIUM FOR HIGH ENERGY CALIBRATION

The 11th Annual Meeting of the International Astronomical Consortium for High Energy Calibration (IACHEC) was held at IUCAA during February 29- March 3, 2016.
[For details see Khagol, No.106, April 2016]

INDO-KOREAN WORKSHOP ON GRAVITATIONAL WAVES

Indo-Korean Workshop on Gravitational Waves was hosted by IUCAA during January 28-29, 2016. The workshop was coordinated by Sukanta Bose.
[For details see Khagol, No.106, April 2016]

Ph.D. Programme

Five IUCAA Research Scholars have defended their Ph.D. theses, namely: Pallavi Bhat (Guide: Kandaswamy Subramanian), Santanu Das (Guide: Tarun Souradeep), Hamsa Padmanabhan (Guide: R. Srianand), Krishnamohan Parattu (Guide: T. Padmanabhan), and Kaustubh Vaghmare (Guide: Ajit Kembhavi and Ranjeev Misra). The Ph.D. degree have been awarded by the Jawaharlal Nehru University, New Delhi, during the year of this report. The synopses of their theses are given below :

Pallavi Bhat

Magnetic Fields in the Universe: Understanding their Origin and Evolution

The presence of ordered magnetic fields is universal. They exist in stars, galaxies and galaxy clusters and influence important physical processes in these astrophysical systems. The origin of cosmic magnetic fields is thought to be the result of *turbulent dynamo* amplification of weak seed fields. Most astrophysical systems are turbulent in nature. This turbulence can then activate dynamos, which convert kinetic energy to magnetic energy. There are two kinds of turbulent dynamos: mean field (or large scale) dynamos, which amplify fields on scales larger than the energy carrying outer eddy scale and fluctuation (or small scale) dynamos, which amplify fields on scales smaller than the outer eddy scale. While mean field dynamos require special conditions such as helicity in the underlying turbulent flow, fluctuation dynamos can operate in non-helical turbulence, on much faster eddy turn over time scales. Thus, fluctuation dynamos will be important in all astrophysical systems, from young galaxies (where they probably generate the first fields) to galaxy clusters and intergalactic filaments (where conditions for mean-field dynamo action are likely to be absent). In this thesis, we have studied turbulent dynamos which includes improving their existing model analytically and resolving outstanding issues related to generation of *coherent* fields using direct numerical simulations and understanding implications for their astrophysical applications.

We begin with research on the fluctuation dynamos. Fluctuation dynamos are generic to turbulent astrophysical systems. A random flow with modest magnetic Reynolds number $\mathrm{R}_M \sim 100$ is sufficient to excite the fluctuation dynamo (FD). The thesis first addresses the FD problem in the kinematic stage. The only analytical model of FD, due to Kazantsev, assumes the velocity to be delta-correlated in time. This assumption breaks down for any realistic turbulent flow. We generalize the analytic model of FD to include the effects of a finite correlation time τ, using renewing flows. We derive a generalized evolution equation for the longitudinal correlation function M_L, which leads to the standard Kazantsev equation in the $\tau \to 0$ limit, and extends it to the next order in τ. We find that this evolution equation involves also third and fourth spatial derivatives of M_L, indicating that the evolution for finite τ will be non-local in general. In the perturbative case of small-τ (or small Strouhl number), it can be recast using an approach due to Landau-Lifschitz, to one with at most second derivatives of M_L. Using both a scaling solution and the WKBJ approximation, we show that the dynamo growth rate is reduced when the correlation time is finite. Interestingly, to leading order in

τ, we show that the magnetic power spectrum, preserves the Kazantsev form, $M(k) \propto k^{3/2}$, in the large k limit, independent of τ.

The thesis then turns to the problem of FD in the saturated state. A central question is whether the fields concentrated on small resistive scales in kinematic regime then grow to larger scales, once Lorentz force becomes important? This will have implications for the astrophysical applications and also to understand mean field dynamos. Towards this, we have run direct numerical simulations (DNS) of FD in periodic boxes up to resolutions of 1024^3, with varying fluid and magnetic Reynolds numbers. We show that the magnetic integral scale L_{int}, increases in all the runs, as Lorentz forces become important to saturate the dynamo. It appears that due to the ordering effect of the Lorentz forces, L_{int} of the saturated field tends to a modest fraction, $1/3 - 1/4$ of the integral scale of the velocity field, for all our runs. We then focus on one observational signature: the random Faraday rotation measure (RM) due to polarized radio emission of background sources seen through the intermittent magnetic field generated by FD. We use the periodic box simulations to directly measure the resulting random RMs. We show that even though the magnetic field generated is intermittent, it still allows for contributions to the RM to be significant. When the dynamo saturates, the rms value of RM is of order 40 - 50% of the value expected in a model where fields of strength B_{rms} uniformly fill cells of the largest turbulent eddy but are randomly oriented from one cell to another. This level of RM dispersion obtains across different values of magnetic Reynolds number and Prandtl number explored. We also use the random RMs to probe the structure of the generated fields to distinguish the contribution from intense and diffuse field regions. We find that the strong field regions (say with $B > 2B_{rms}$) contribute only of order 15 - 20% to the RM. Thus, rare structures do not dominate the RM; rather the general 'sea' of volume filling fluctuating fields are the dominant contributors. These results are then applied to discuss the Faraday rotation signatures of FD generated fields in young galaxies, galaxy clusters and intergalactic filaments.

We continue our study of FD saturation here, by following a different approach using Zeldovich STF map dynamos, which provided a breakthrough in conceptual understanding of fast dynamos, including the small scale FD. We study the evolution and saturation behaviour of two types of generalized Baker's map dynamos, which have been used to model Zeldovich's STF dynamo process. Using such maps allows one to analyze dynamos at much higher magnetic Reynolds numbers R_M as compared to direct numerical simulations. In the 2-strip map dynamo, there is constant constructive folding while the 4-strip map dynamo also allows the possibility of a destructive reversal of the field. The growing $B(x)$ approaches a shape invariant eigenfunction independent of initial conditions, whose fine structure increases with increasing R_M. Its power spectrum $M(k)$ displays sharp peaks reflecting the fractal nature of $B(x)$ above the diffusive scale.

We explore the saturation of these dynamos in three ways: via a renormalized reduced effective R_M (Case I) or due to a decrease in the efficiency of the field amplification by stretching, without changing the map (Case IIa), or changing the map (Case IIb), and a combination of both effects (Case III). For Case I, we show that $B(x)$ in the saturated state, for both types of maps, approaches the marginal eigenfunction, which is obtained for $R_M = R_{crit}$ independent of the initial $R_M = R_{M0}$. On the other hand in Case II, for the 2-strip map, we show that $B(x)$ saturates preserving the structure of the kinematic eigenfunction. Thus, the energy is transferred to larger scales in Case I, but remains at the smallest resistive scales in Case II as can be seen from both $B(x)$ and $M(k)$. For the 4-strip map, $B(x)$ oscillates with time, although with a structure similar to the kinematic eigenfunction.

Interestingly, the saturated state in Case III shows an intermediate behaviour, with $B(x)$ similar to the kinematic eigenfunction at an intermediate $\mathrm{R}_M = R_{sat}$, with $R_{M0} > R_{sat} > R_{crit}$. R_{sat} is determined by the relative importance of the increased diffusion versus the reduced stretching. These saturation properties are akin to the range of possibilities that have been discussed in the context of FD.

In DNS of helically forced turbulent dynamos, it is seen that in the kinematic regime, the growing magnetic energy spectrum remains shape-invariant, i.e., at each wavenumber k, the spectrum grows with the same growth rate. However, the strength of the large-scale field is seen to diminish with increasing magnetic Reynolds number R_M. This arises due to the magnetic energy spectrum still peaking at resistive scales, even when helicity is present. We study how this scenario changes on saturation, when the Lorentz force becomes important. We find that as the field grows, the power shifts from the resistive scales to larger and larger scales. The final saturated state has a strong large scale helical field even for large R_M. Thus, large scale dynamos can indeed be substained even in the presence of strongly growing fluctuations. We have run DNS of 1024^3 resolution and large R_M, unto saturation to identify the growing mean field after the saturation of FD.

Using a simple two-scale model, Blackman and Subramanian (Paper I) found that sufficiently strong large scale helical magnetic fields are resilient to turbulent diffusion, decaying on resistively slow rather than turbulently fast time scales. This bolsters fossil field origins for magnetic fields in some astrophysical objects. Here, we study this process through DNS of decaying large scale helical magnetic fields in the presence of non-helical turbulence. We consider two cases: (1) the initial helical field is large enough to decay resistively but transitions to fast decay; (2) the case of Paper I, wherein the transition energy for the initial helical field to decay fast directly is sought. Simulations and two-scale modelling (based on Paper 1), reveal the transition energy, E_{c1} to be independent of the turbulent forcing scale, within a small range of R_M. For case (2), the two-scale theory predicts a large scale helical transition energy of $E_{c2} = (k_1/k_f)^2 M_{eq}$, where k_1 and k_f are the large scale and small turbulent forcing scale wavenumbers respectively and M_{eq} is the equipartition magnetic energy. The DNS agree qualitatively with this prediction, but the R_M currently achievable, is too small to satisfy a condition $3/R_M << (k_1/k_f)^2$, necessary to robustly reveal the transition E_{c2}. The two scale theory and DNS agree wherever they can be compared, suggest that E_{c2} of Paper I should be identifiable at higher R_M in DNS.

The organization of this thesis is as follows.

- **Chapter 1** provides a brief introduction to observations of coherent magnetic fields, followed by introduction to turbulent dynamo theory, with an emphasis on the fluctuation dynamos. This is followed by a summary of the outstanding problems in turbulent dynamo theory which form the motivation for this thesis work.

- In **Chapter 2**, we study the problem of FD in kinematic regime analytically. We improve on the existing model of FD by incorporating effects of finite time correlation in the underlying fluid flow.

- In **Chapter 3**, we then study the coherence scale evolution of magnetic fields using direct numerical solutions of FD for various R_M and P_M. This is followed up by estimation of the resulting random Faraday rotation signatures of the saturated FD fields.

- In **Chapter 4**, we further our understanding of FD saturation by exploring different saturation mechanisms for Zeldovich STF map dynamos.
- **Chapter 5** investigates the mean field dynamo in the presence of FD for large R_M using DNS.
- In **Chapter 6**, we explore the possibility of fossil field origins for magnetic fields given that they are helical to start with.
- **Chapter 7** presents a discussion of our results and conclusions for the thesis.

Santanu Das

Challenges in Inferring New Physics from Cosmic Microwave Background Observations

Cosmic microwave background (CMB) is one of the most important field of study in the present physics. It is driving several important and exciting research in theoretical cosmology and CMB data analysis. The author has worked both on the theory, as well as, the data inference challenges of CMB.

On the theoretical front of research in CMB, one of the most important task is to efficiently compute the power spectrum of CMB fluctuations for different theoretical cosmological models at high level of accuracy such that they can be tested against increasingly refined observations. Several Boltzmann codes such as CMBFAST, CAMB, CLASS, etc. are publicly available for use in cosmology for calculating the CMB power spectrum. We have developed a new independently written CMB line of sight Boltzmann numerical package CMBAns (Cosmic Microwave Background Anisotropy numerical simulation) for calculating the CMB power spectrum.

In Chapter 2, we briefly describe the equations and approximations used in CMBAns for calculating the CMB power spectrum. CMBAns is capable of calculating the CMB power spectrum for both scalar and tensor perturbations. We provide detailed equations of scalar and tensor perturbations and the approximation schemes used in solving the equations numerically. We discuss the errors involved in using various approximation schemes and also present a comparison of the results obtained using CMBAns and CAMB.

Recent results of Planck in 2013 reveal that the power in the low multipoles of CMB angular power spectrum, approximately up to $l = 30$, is significantly lower than that theoretically predicted in the best fit ΛCDM model. There are different known physical effects that can affect the power at low multipoles, such as features in the primordial power spectrum (PPS) in some models of inflation and ISW effect. In Chapter 3, we investigate the possibility of invoking the Integrated Sachs-Wolfe (ISW) effect to explain the power deficit at low multipoles. The ISW effect that originates from the late time expansion history of the universe is rich in possibilities given the limited understanding of the origin of dark energy (DE). It is a common belief that the ISW effect adds to the power at the low multipoles of the CMB angular power spectrum. We carry out an analytic study to show that there are some expansion histories in which the ISW effect, instead of adding power, provides negative contribution to the power at low CMB multipoles. Guided by the analytic study, we present examples of the features required in the late time expansion history of the universe that could explain the power deficiency through the ISW effect. We also show that an ISW origin of power deficiency is consistent at present, with other cosmological observations that probe the expansion history such as distance modulus, matter power spectrum and the evolution of cluster number count. We also show that the ISW effect may be distinguished from power deficit originating from features in the PPS using the measurements of the CMB polarization spectrum at low multipoles expected from Planck. We conclude that the power at low multipoles of the CMB anisotropy could well be closely linked to Dark Energy puzzle in cosmology, and this observation could be actually pointing to richer phenomenology of DE beyond the cosmological constant Λ.

In Chapter 4, we focus on the cosmological parameter estimation. Markov Chain Monte Carlo (MCMC) sampler is widely used for cosmological parameter estimation from CMB and other data. However, due to the intrinsic serial nature of the MCMC sampler, convergence is often very slow. Therefore, we present a fast and independently written Monte Carlo method for cosmological parameter estimation named Slick Cosmological Parameter Estimator (SCoPE), that employs delayed rejection to increase the acceptance rate of a chain, and pre-fetching that helps an individual chain to run on parallel CPUs. An inter-chain covariance update is also incorporated to prevent clustering of the chains allowing faster and better mixing of the chains. We use an adaptive method for covariance calculation to update the covariance automatically as the chains progress. Our analysis shows that the acceptance probability of each step in SCoPE is more than 95% and the convergence of the chains are faster. Using SCoPE, we carry out some cosmological parameter estimations with different cosmological models using WMAP-9 and Planck results. One of the current research interests in cosmology is to quantify the nature of dark energy. We analyze the cosmological parameters from two illustrative commonly used parametrization of dark energy models. We also asses that the primordial helium fraction in the universe can be constrained by the present CMB data from WMAP-9 and Planck. The results from our MCMC analysis demonstrate the ability of SCoPE method, and also provides a completely independent estimation of cosmological parameters from WMAP-9 and Planck data.

Estimation of parameters of the standard model of cosmology have dramatically improved over past few decades due to increasingly exquisite measurements made by Cosmic Microwave Background (CMB) experiments. Recent data from Planck matches well with the minimal ΛCDM model. A likelihood analysis using Planck, WMAP and a selection of high resolution experiments (highL), limits the tensor to scalar ratio $r_{0.002} < 0.11$ when $dn_s/d\ln k = 0$. Planck also imposes an upper bound on neutrino mass $\sum m_\nu < 0.23$ eV using Planck + WMAP + highL + BAO likelihood. However, results from BICEP 2 claims the detection of $r = 0.2^{+0.07}_{-0.05}$ from polarization spectra. Further, results from SDSS-III BOSS large scale galaxy survey constrains the total neutrino mass to $\sum m_\nu = 0.36 \pm 0.10$eV . It is important to study the consequences of these new measurements on other cosmological parameters. Therefore, in Chapter 5, we assess the revised constraints on cosmological parameters in light of these two measurements that are in some tension with the constraints from Planck.

In Chapter 6, using a modified version of CMBAns, that allows us to modify $H(z)$ to include any arbitrary given feature at any redshift, we study the effect of changes in the expansion history of the

Universe on the CMB power spectrum. Motivated by the detailed analytical calculations of the effects of the changes in $H(z)$ on ISW plateau and CMB low multipoles, we study two phenomenological parametric form of the expansion history using WMAP data and through MCMC analysis. Our MCMC analysis shows that the standard ΛCDM cosmological model is consistent with the CMB data allowing the expansion history of the Universe vary around this model at different redshifts. However, our analysis also shows that a decaying dark energy model proposed in has in fact a marginally better fit than the standard cosmological constant model to CMB data. Concordance of studies presented in this chapter with the previous analysis done by other groups showing that Baryon Acoustic Oscillation (BAO) and supernovae data (SN Ia) also prefer mildly this decaying dark energy model to ΛCDM, makes this finding interesting and worth further investigation.

Any cosmological parameter estimation requires a proper posterior of Cl from the observed skymap. Provided the CMB sky is statistically isotropic, the CMB angular power spectra are the only valuable quantities that we can derive from observation. However, in absence of the isotropy violation, we also need the BipoSH coefficients along with the CMB power spectrum to adequately describe the CMB sky. A prior assumption of statistical isotropy in such case not only provides us suppressed information, but also leads to wrong posterior of the CMB power spectra. Therefore, proper inference of the observational data is necessary. Therefore, in Chapter 7, we derive a general formalism for Bayesian inference of the underlying covariance for random fields over a sphere. We use the BipoSH representation to describe general covariance matrices on the sphere. This provides a principled approach to study the breaking of statistical isotropy. We apply this formalism on the CMB maps that include isotropy violation features due to physical and experimental issues such as Doppler boost, weak lensing, scan pattern and non-circular beam, masking, anisotropic noise, non-standard topology of the universe, etc. This approach gives the way to a quantitative evolution of the evidence for anomalies violating SI in the CMB sky by estimating the BipoSH coefficients along with their complete posterior.

After cosmological data inference, we focus on describing the research work on the CMB observational and data analysis aspects. A number of studies of WMAP and Planck claimed the low multipole (specially quadrupole) power deficiency in CMB power spectrum. Anomaly in the orientations of the low multipoles have also been claimed. There is a possibility that the power deficiency at low multipoles may not be of primordial origin and is only an observation artifact coming from the scan procedure adapted in the WMAP or Planck satellites. Therefore, it is always important to investigate all the observational artifacts that can mimic them. The CMB dipole which is much higher than the quadrupole can leak to the higher multipoles due to the non-symmetric beam shape of the WMAP or Planck. In Chapter 8, we show that a non-negligible amount of power from the dipole can get transferred to the quadrupole and the higher multipoles due to the non-symmetric beam shapes and contaminate the observed measurements. The orientation of the quadrupole generated by this power transfer is surprisingly very close to the quadrupole observed from the WMAP and Planck maps. However, our analysis shows that the orientation of the quadrupole cannot be explained using only the dipole power leakage. We calculate the amount of quadrupole power leakage for different WMAP bands. For Planck experiment (work carried out prior to release of results and experimental details) we present the results in terms of upper limits on asymmetric beam parameters that can lead to significant amount of power leakage.

Measurement of CMB anisotropies has been playing a lead role in precision cosmology by providing some of the tightest constrains on cosmological models and parameters. However, precision can only be meaningful when all major systematic effects are taken into account. Non-circular beams in CMB experiments can cause large systematic deviation in the angular power spectrum, not only by modifying the measurement at a given multipole, but also introducing coupling between different multipoles through a deterministic bias matrix. Therefore, in Chapter 9, we add a mechanism for emulating the effect of a full bias matrix to the Planck likelihood code through the parameter estimation code SCoPE. We show that if the angular power spectrum was measured with a non-circular beam, the assumption of circular Gaussian beam or considering only the diagonal part of the bias matrix can lead to huge error in parameter estimation. We demonstrate that at least for elliptical Gaussian beams, use of scalar beam window functions obtained via Monte Carlo simulations starting from a fiducial spectrum, as implemented in Planck analysis for example, leads to only few percent of sigma deviation of the best-fit parameters. However, we notice more significant differences in the posterior distributions for some of the parameters, which would in turn lead to incorrect error bars. These differences can be reduced, so that the error bars match within a few percent, by adding an iterative reanalysis step, where the beam window function would be recomputed using the best-fit spectrum estimated in the first step.

Though CMB signal is believed to be statistically isotropic (SI), WMAP-reported a detection of SI violation signal. Therefore, to study the origin of the SI violation signal in the CMB sky, we simulate CMB maps using actual WMAP non-circular beams and scanning strategy. Chapter 10 shows that estimated BipoSH spectra from these maps match the WMAP-7 results very well. This is the first explicit and conclusive demonstration that the SI violation reported in WMAP-7 maps is due to the non-circularity of the beams. It is also evident that only a very careful and adequately detailed modelling, as carried out here, can conclusively establish that the entire signal arises from non-circular beam effect. This is important since cosmic SI violation signals are expected to be subtle and dismissing a large SI violation signal as observational artifact based on simplistic 'plausibility' arguments run the serious risk of throwing the 'baby with the bathwater'.

In the concluding Chapter 11, we summarize the thesis and briefly discuss the future prospects of research in this field.

Hamsa Padmanabhan

Probes of the Evolving Universe

The last few decades have witnessed several rapid advances in the field of observational cosmology. Today, we have probes of the Universe over a wide range of wavelengths from the radio to the X-ray bands. The physics of the formation of structures in the Universe, the epoch and evolution of reionization and the cosmic microwave background radiation each encode a vast store of information on the evolution history of the universe, spanning a wide range of redshifts. The wealth of observational data has led to the development of 'precision cosmology', whereby the cosmological parameters are measured to unprecedented accuracy with the available data. The fact that all the independent observational constraints are consistent with the 'standard model' of theoretical cosmology is one of the most impressive successes of the theory. However, the standard model of cosmology also leaves us with several challenging problems. About 70% of the present-day energy density of the Universe is in the form of 'dark energy', a component that behaves like a smooth fluid having negative pressure, and leads to the accelerated expansion. This component is consistent with a cosmological constant term in Einstein's equations. Another 25% is in the form of 'dark matter' — which does not interact with radiation, but participates in gravitational clustering. We do not have a physical understanding of (or laboratory evidence for) either of these two components, which together comprise more than 95% of the present-day Universe. Only the remaining 4% of the energy density is in the form of baryonic material (with a tiny amount in the form of radiation), whose physical properties are familiar to us.

A key issue in observational cosmology consists of tracing the evolution of the baryonic material in the Universe. At the earliest epochs, radiation decoupled from the neutral baryonic matter in the first major phase transition of the observable Universe known as the epoch of recombination, which occurred about 300,000 years after the Big Bang (redshift $\sim$ 1100). This primordial radiation is observable today as the cosmic microwave background (CMB). Most of the baryonic material in the universe was (and is) in the diffuse component between galaxies, known as the intergalactic medium (IGM). The baryonic matter in the universe was almost fully neutral hydrogen (H I) gas at the end of the epoch of recombination, with small ($\sim$ 10%) amounts of neutral helium (He I) and remained so (a period known as the dark ages of the universe) until the first stars and galaxies formed about a few hundred million years later. These luminous sources contributed ionizing photons to complete the second major phase transition in the observable Universe known as cosmic reionization. In this process, the radiation from starlight was responsible for ionizing the hydrogen and this period which lasted for about a few hundred million years is referred to as the cosmic dawn that immediately followed the dark ages. Studying this epoch, hence, offers valuable clues towards the physics of the baryonic matter in the Universe and the first stars and galaxies.

Helium is expected to be singly ionized around the same time as the reionization of hydrogen and softer spectra from the first stars and galaxies are believed to be responsible for the completion of the reionization of He I. However, harder spectra (with energies of the order of 54.4 eV) are required for the completion of reionization of He II to He III. It is believed that the beginning stages of reionization of He II took place in the near-zones of high-redshift quasars in the early universe. The high energies associated with the reionization of He II were responsible for the injection of large amounts of heat into the intergalactic medium (IGM) as is believed to be indicated by the observed sharp rise in the temperature of the IGM over a billion years (redshifts 6 to 3).

At later epochs (about a few billion years after the Big Bang; redshifts 1.5 to 4), the 21-cm line emission from neutral hydrogen is expected to be a powerful probe of the gas content of the universe. Mapping the distribution of neutral hydrogen has been carried out using a number of approaches: Galaxy surveys, 21-cm intensity mapping experiments without resolving the individual galaxies, and higher-redshift Damped Lyman Alpha (DLA) observations. These studies enable one to constrain the neutral gas distribution in the post-reionization universe. Hence, the study of this period forms an important probe of the later stages of evolution of the Universe.

The current Universe (the last 6 billion years of cosmic time) is characterized by the domination of the cosmological constant, which leads to the late-time accelerating phase of the universe. The extremely small value of the cosmological constant is a major puzzle in current cosmology (known as the cosmological constant "problem").

The research presented in this thesis follows three key themes in the broad area of cosmology and the evolution of the universe: (a) the epoch of reionization and the thermal evolution of the intergalactic medium, (b) neutral hydrogen in the post-reionization epoch of the universe, and (c) an approach towards solving the cosmological constant problem in the backdrop of the emergent paradigm of gravity.

A chapterwise summary of the thesis is given below:

Chapter 1 provides a basic introduction to the concepts in cosmology, structure formation in the Universe and the intergalactic medium. It also provides an overview of the current observations in the field which are relevant for the remainder of the thesis.

In Chapter 2, we study the thermal and ionization state of the intergalactic medium (IGM) and in the near-zones of high-redshift quasars ($z \sim 6$). The reionization of hydrogen is believed to have been completed at redshifts $z \sim 6$. Hence, it is expected that, following the hydrogen reionization epoch, the temperature of the intergalactic medium would exhibit a gradual cooling (due to the adiabatic expansion of the universe, with a correction due to the presence of an ionizing background). However, recent studies of quasar spectra over $z \sim 2-5$ indicate the opposite effect, i.e., gradual *heating* of the IGM is observed from the redshifts of 5 to 2. Recently, it has also been shown that an additional heating effect manifests in the near zones of high-redshift quasars ($z \sim 6$) when compared to the general intergalactic medium at these epochs. Both these trends acquire natural explanations in the event of *helium reionization*, i.e., the He II to He III transition taking place during $z \sim 2-5$. The reionization of He II requires the energy of 54.4 eV, which cannot be provided by the softer spectra of star-forming galaxies, and hence harder spectra, such as those from quasars, are required. The population of bright quasars is found to peak around redshift 2 - 3 and drop rapidly above redshifts of 4. Both the observed effects are, thus, explained by the fact that the additional heating effects in the near-zones percolate to the entire IGM as the quasar population peaks. This, therefore, represents evidence for the initial stages of He II $\rightarrow$ He III reionization taking place in the near-zones of quasars around $z \sim 6$.

We study the above effects in detail with the help of hydrodynamical simulations coupled to a radiative transfer code to analyze the heating of the intergalactic medium. We find that the extent of the region around the quasar within which the additional heating is expected to contribute significantly is strongly influenced by the lifetime of the quasar. This indicates that even if one uses all the H I lines in the quasar spectrum for the temperature measurement, the additional heating effects may be detected as long as the quasar age is sufficiently large ($\sim 10^8$ years). We find that a recently introduced statistic, known as the curvature of the spectrum, is a very good estimator of the effects of additional heating in the quasar near-zones since it directly captures the effects of temperature. We also find that the curvature statistic is far more effective in this regard than the flux pdf statistic, and may be used to distinguish the effect of additional heating over and above the individual cosmic variance of the samples.

The temperature-density relation of the high-redshift intergalactic medium is well-described by a power law "effective" equation of state, $T(\Delta) = T_0\Delta^{\gamma-1}$. Both the parameters of this equation of state are influenced by the reionization history of the Universe. Hence, it is important to accurately determine the values of T_0 and γ at every redshift to place constraints on hydrogen and helium reionization. In the literature, it has been found that the mean curvature statistics provides very accurate constraints on the temperature of the intergalactic medium at a characteristic overdensity Δ at each redshift — in other words, the mean curvature does not constrain T_0 and γ separately, but instead constrains the combination $T(\Delta)$. In Chapter 3, we use hydrodynamical simulations to extend this existing approach towards estimating both the parameters T_0 and γ at each redshift, from the mean, median and percentiles of the curvature distribution. This provides a method towards stringent constraints on T_0 and γ without resorting to computationally intensive approaches like Voigt profile fitting of the spectra.

Chapters 4 and 5 deal with the distribution of neutral hydrogen in the post-reionization universe. At redshifts $z \sim 0 - 5$, neutral hydrogen (H I) exists in the form of dense clumps in galaxies, Lyman-limit systems and Damped Lyman-Alpha systems (DLAs). At low redshifts ($z \sim 0 - 1$), 21-cm emission line surveys of galaxies, and H I intensity mapping experiments are used as probes of the neutral hydrogen distribution. The limits of current radio facilities, however, hamper the detection of 21-cm in emission above redshifts of $z \sim 0.1$ from normal galaxies. At intermediate redshifts, the H I distribution is studied via Damped Lyman-Alpha systems (DLAs), which are also known to be the primary reservoirs of neutral hydrogen at these epochs. In Chapter 4, we provide a compilation of the currently available constraints on the evolution of H I from the available theoretical and observational data — galaxy surveys, H I intensity mapping experiments, Damped Lyman-Alpha systems, theoretical prescriptions for assigning H I to dark matter haloes, and the results of numerical simulations. We find that it might be possible to improve upon the commonly used assumption of constant H I fraction and bias parameter across redshifts, by taking into account the fuller picture implied by the current constraints. Using a minimum variance interpolation scheme, we then obtain the predicted uncertainties on the H I intensity fluctuation power spectrum across redshifts 0 - 3.5 for three different confidence scenarios, and discuss the consequences for the measurement of the power spectrum by current and future intensity mapping experiments.

In Chapter 5, we review the existing approaches in the literature towards modelling the 21-cm and DLA based observations. We attempt to reconcile the approaches towards a consistent model of the distribution and evolution of H I across redshifts. We extend a physically motivated, 21-cm based model to also account for the DLA observables. We derive the various quantities such as the DLA column density distribution and incidence, as well as the evolution of the H I density parameter and clustering across redshifts. The prescription favours the abundance of H I in dark matter haloes with virial velocities between 30 km/s and 200 km/s, which is consistent with the results of recent numerical simulations and imaging surveys. We discuss the implications of our findings for the characteristic host halo masses of the DLAs and the power spectrum of 21-cm intensity fluctuations.

The last part of the thesis (Chapter 6) deals with the cosmological constant problem. We provide a possible solution in the backdrop of the emergent perspective of gravity. We first provide a brief overview of the conventional approach to cosmology in which the Friedmann equation is used to describe the dynamical evolution of the universe. We then describe an alternative, epoch invariant parameterization of cosmology in which the Friedmann equation is now parametrized by a set of variables whose values are manifestly independent of the epoch at which they are measured. Using this epoch invariant parametrization, we construct a dimensionless number (which, We call CosMIn), which counts the number of modes within a Hubble volume that cross the Hubble radius from the end of inflation to the beginning of the late-time accelerating phase. Theoretical arguments suggest the value of CosMIn to be equal to 4π. We show how the introduction of CosMIn and the postulate that CosMIn $= 4\pi$ allows us to determine the correct, observed value of the cosmological constant for a GUTs scale inflation and the allowed range in the matter and radiation energy densities as determined from cosmological observations. In the later part of the chapter, we discuss the cosmological constant problem in the backdrop of the emergent gravity paradigm, in which the postulate that CosMIn $= 4\pi$ acquires a natural explanation. This provides a fundamental physical principle that determines the value of the cosmological constant. We discuss the results and consequences for a novel and alternate description of cosmology.

The conclusions of the thesis are briefly summarized in Chapter 7. We also describe how some of the results in the thesis may be extended in future work.

Krishnamohan Parattu

Structure of Gravitational Theories with Focus on the Emergent Paradigm

General relativity is a beautiful and successful theory. But there are many reasons to believe that it is not complete. One reason is the presence of singularities in the theory, and hence, its loss of predictability, in many physical situations. Another reason is the discovery that horizons in general relativity seem to have thermodynamic properties like temperature and entropy. Within the framework of general relativity, this phenomenon is an observation without a natural explanation and provides another motivation to probe the theory. (The meaning of this statement becomes clearer when compared with the phenomenon of equivalence of gravitational and inertial masses, which has the status of an observation in Newton's theory of gravitation but is a natural consequence of general relativity.) A third reason is the fact that all the other known interactions, electromagnetic, weak and strong, are described by quantum theories while gravity alone is still described by a classical theory in general relativity. Because of this fact, there is general consensus in the community that a quantum theory of gravity awaits discovery. The attempts to develop general relativity into a perturbative quantum field theory, taking a cue from the quantization of the other forces, has not succeeded thus far. This suggests that we need to modify our understanding of quantum field theory or our understanding of general relativity or both.

In this thesis, we shall take a closer look at the structure of general relativity. We shall mainly analyze the structure of the variational principle in general relativity and the connection between gravity and thermodynamics. Apart from the introduction and the conclusion, the thesis is divided into three parts.

In the first part of the thesis, we examine the action principle of standard general relativity. More specifically, we look at the variational principle that uses the Einstein-Hilbert action to arrive at

Einstein's equations. It is well-known that this variational principle is not well-posed as we have to fix both the metric and its normal derivatives at the boundary to set the boundary term in the variation to zero. In general, such a procedure will lead to inconsistencies with the equations of motion. Motivated by this observation, we examine the structure of the boundary term arising from the variation of the Einstein-Hilbert action and prove that when a certain set of dynamical variables and their canonical momenta (with respect to the Γ^2 Lagrangian) are used, the boundary term can be set to zero by fixing just the canonical momenta at the boundary. Thus, we see that the Einstein-Hilbert action has a special structure. In particular, having only the canonical momenta to be fixed at the boundary avoids a potential conflict with quantum theory that could arise if one attempts to fix both the variables and their momenta at the boundary. We then argue that the Einstein-Hilbert Lagrangian may be better thought of as a momentum-space Lagrangian. If Einstein-Hilbert Lagrangian exhibits this structure when treated in terms of a particular dynamical variable and its corresponding canonical momenta, the variable-momenta pair is termed as an HCV (Holographically Conjugate Variables). We also show that many standard formulae in general relativity take on a simpler form if we express them in terms of the HCV $\left(f^{ab} = \sqrt{-g}g^{ab}, N^c_{ab} = -\Gamma^a_{bc} + \frac{1}{2}(\Gamma^d_{bd}\delta^a_c + \Gamma^d_{cd}\delta^a_b)\right)$.

We next examine another standard solution to the problem of the well-posedness of the variational principle of general relativity. The most widely accepted prescription is to add an additional boundary term to the action principle, called a counter-term, so that only the metric needs to be fixed on the boundary when the modified action is varied. Although, there are many proposed counter-terms available in the literature, the most popular is the one introduced by Gibbons, Hawking and York, known as the Gibbons-Hawking-York (GHY) counter-term. But this counter-term is well-defined only when the boundary to the spacetime volume under consideration is space-like or time-like, since its construction involves the unit normal and the induced non-degenerate 3-metric to the boundary surface. In fact, there is no well-defined counter-term in the literature for null boundaries.

We use a method introduced by Padmanabhan to arrive at the GHY counter-term from first principles and apply it to the case of a null boundary. This method enables us to arrive at a counter-term that can be used on a null boundary. The analysis also illuminates the nature of the degrees of freedom that need to be fixed on the null boundary. For a non-null boundary, the standard analysis specifies the spatial metric $h_{\alpha\beta}$ to contain the degrees of freedom to be fixed on the boundary. Using the freedom of three spatial diffeomorphisms, the six degrees of freedom in $h_{\alpha\beta}$ can be reduced to three, but there is no natural way to choose the degrees of freedom to be eliminated. For a null boundary, we show that the six degrees of freedom in h_{ab} are transferred to the three degrees of freedom in ℓ^a, the normal vector to the null surface, and the three degrees of freedom in q^{ab}, the metric of the 2-surface on the null surface orthogonal to the chosen auxiliary null vector k^a, and that it is convenient to eliminate the three degrees of freedom in ℓ^a using the freedom of diffeomorphisms on the null surface. This leaves the three degrees of freedom in q^{ab} as the degrees of freedom to be fixed on the null surface.

Encouraged by this success, we attempt a more general analysis, and try to find a counter-term that can be used on a boundary regardless of whether it is null, space-like or time-like. Supplementing the normal with an auxiliary vector, we are able to perform the analysis to obtain a counter-term that can be used on a general boundary to eliminate the normal derivatives of the metric. For appropriate choices of the auxiliary vector, this counter-term reduces to the GHY counter-term or the counter-term that we obtained for null surfaces previously. Next, we try to see if we can specify the degrees of freedom that may be fixed on the boundary surface regardless of whether the surface is null or non-null. Although, we are not able to arrive at a single prescription that can be used on any type of boundary, we identify a natural forking point in the course of the analysis, where one fork corresponded to non-null surfaces and the other to null surfaces. Each fork, when followed through to the end, gives us the well-known results for non-null surfaces and our previous results for null surfaces, respectively. We also take the null limits of the Einstein counter-term and the GHY counter-term and compare them with our proposed counter-term for a null surface. We show that although the three expressions are distinct, the normal derivative terms in all of them are equal. Hence, their variations give equal contributions to the action when the metric is fixed on the boundary.

The second part of the thesis deals with the thermodynamical aspects of null surfaces. First, we consider the boundary term in the variation of the Einstein-Hilbert action integrated over a null surface and show that it can be interpreted as $S\delta T$, S being the entropy and T the temperature of the null surface, under certain assumptions. This boundary term is the integral of the normal component of $f^{ab}\delta N^c_{ab}$ integrated over the boundary. Considering the integral of the normal component of $N^c_{ab}\delta f^{ab}$ integrated over the boundary, we find that it gives us $T\delta S$, thus revealing an intriguing connection between HCVs and thermodynamic quantities on the null surface.

Second, we study the interpretation of Einstein equations near a horizon as a thermodynamic identity. Previous results have been obtained for horizons in spacetimes with special symmetries, such as staticity or spherical symmetry. We show that a thermodynamic interpretation can be provided to a particular component of the Einstein equation near an arbitrary null surface in an arbitrary spacetime. To obtain this result, we use Gaussian null coordinates that can be defined in the region near any null surface. Further, we use an approach making use of Noether currents. We use the Noether current for a time-development vector that we choose, and show that three different projections of this current give us three different results available in the literature. The projection along the auxiliary vector k^a gives us our thermodynamic identity, while the projection along ℓ^a gives us the generalization of the results presented by Jacobson in [arXiv:gr-qc/9504004] and the projection along q^a_b gives us the result that Einstein equations projected on a null surface has the structure of the Navier-Stokes equation of fluid dynamics [arXv:gr-qc/1012.0119].

The third part of the thesis deals with the issue of emergence of classicality in quantum systems. The favoured paradigm in the literature for explaining the classical world emerging from quantum physics is that systems are not isolated and that the apparent classical behaviour of the system under consideration arises because the degrees of freedom of myriad other systems interacting with our system have not been taken into consideration. This is the paradigm of quantum decoherence. But this paradigm fails to come up with an answer when confronted with the universe as a whole. The universe we live in appears to be classical, but we do know that early universe was quantum in nature. How did the isolated system, that is the universe evolve from a quantum state and achieve classicality? In an effort towards answering this question, we consider an isolated system and see if it can evolve to classicality by itself. The system that we consider consists of two coupled oscillators. By tuning the coupling strength, we are able to show that there is a certain regime in which the evolution of the system itself drives it towards classicality, classicality which is being measured using a criterion of our choosing.

We shall now give chapter-wise summary of the thesis. The thesis is divided into five parts comprising a total of ten Chapters.

The introductory part of the thesis is Chapter 1, that discusses the motivation for our work and introduces some necessary background material.

The second part, comprising Chapter 2, Chapter 3, Chapter 4 and Chapter 5, deal with the dynamics of general relativity.

In Chapter 2, the standard action principle for general relativity, based on the Einstein-Hilbert action, is introduced, the boundary conditions are discussed and the alternate Palatini formulation is also presented.

In Chapter 3, we motivate the introduction of HCVs by examining the structure of the boundary term in the variation of general relativity and discovering that only the canonical momenta need to be fixed at the boundary when working in terms of these variables. Then, we consider the standard structure of general relativity in terms of the HCV $(f^{ab}, N^c_{ab}$, and show that many manipulations and formulae become much simpler in terms of these variables.

In Chapter 4, we investigate what counter-term has to be added to the Einstein-Hilbert action when the boundary is a null surface in order to make the variational principle well-posed. By analyzing the structure of the boundary term in the variation of the Einstein-Hilbert action, we come up with a counter-term that can be added in the presence of a null boundary. Our analysis also reveals that the freedom of diffeomorphisms can be used to arrange matters such that only the 2-metric on the null surface, q_{ab}, needs to be fixed on the null boundary.

In Chapter 5, we analyze this result further by looking at our counter-term for null surfaces as well as the direct null limits of the Einstein counter-term and the GHY counter-term. We also present a single counter-term that can be used on a null or non-null surface, and an analysis of the degrees of freedom that need to be fixed on the boundary surface. This analysis naturally splits into the null and non-null cases and recovers previous results in the literature.

In the third part, containing Chapter 6, Chapter 7 and Chapter 8, we are concerned with the connection between general relativity and thermodynamics.

In Chapter 6, we provide a brief introduction to the connection. In Chapter 7, we show that there seems to be an interesting connection with HCVs and thermodynamics. If we take an HCV, say (f^{ab}, N^c_{ab}), then we find that the integral of $f^{ab}\delta N^c_{ab}$'s projection over a horizon when integrated over a null surface, under some assumptions, gives $S\delta T$. Similarly, if we use the integral of $N^c_{ab}\delta f^{ab}$, we obtain $T\delta S$.

In Chapter 8, we extend previous results that showed that Einstein's equations near a horizon can be interpreted as a thermodynamic identity for static spacetimes. We show that similar results hold near any null surface in an arbitrary spacetime.

The fourth part, made up of a single chapter Chapter 9, discusses the emergence of classicality in quantum systems. We consider a toy model of two coupled oscillators. By tuning the coupling strength, we find that the system can spontaneously evolve to classical behaviour, according to a criterion of our choice, for couplings which are strong enough.

The concluding part is made up of Chapter 10, giving the summary of the thesis and presenting the future outlook.

Kaustubh Vaghmare

Structure, Properties, and Formation Histories of S0 Galaxies

Galaxies are the basic building blocks of the large scale structure of the Universe. They comprise a large number (10^{6-12}) of stars, gas, dust and dark matter, and present themselves in a variety of morphologies. The first attempt at classification of galaxies was the famous tuning fork diagram proposed by Hubble (1936). In this scheme, the elliptical shaped galaxies are placed on the left hand side and comprise a single component of stars. The spiral galaxies, both barred and unbarred are placed on the right, arranged in the decreasing order of the bulge size and winding of the spiral arms. These galaxies, at minimum, are made of two basic stellar components namely the central bulge and the outer disk. Apart from these two classes, there are also galaxies which have a bulge and a disk but contain no spiral arms. These are known as S0 galaxies. As a large fraction of these are found to contain a lens-like structure in their disk, they are also known as lenticular galaxies.

Any classification scheme in any branch of science cannot be a random collection of objects. The scheme should capture the inter-relationships between the various classes and their broad properties. Hubble originally placed the S0 galaxies in between the ellipticals and spirals as a single class. Several decades later, the tuning fork continues to remain a starting point for any introductory treatment on galaxies. However, the implication of this position given to S0 galaxies can be debated. The Hubble tuning fork suggests that the S0 galaxies are all alike, have properties intermediate to ellipticals and spirals, and are a transition class. In recent decades, observational evidence suggests that this class encompasses a diverse range of objects with vastly different properties and hence formation histories.

When S0s are taken as a single class of objects and the correlations between their structural properties are investigated, they show a large scatter. In other words, they don't follow the trends otherwise followed by ellipticals or by spiral galaxies. However, Barway e al. (2007,2009) show that it is possible to divide S0 galaxies into two bins of luminosity. The *bright* S0s and *faint* S0s behave differently indicating a different formation process at work. In particular, the bright S0s are more like elliptical galaxies and have likely formed in a similar manner viz. by hierarhical clustering and through mergers at an early epoch. The faint S0s on the other hand show signs of having formed through secular processes over a much larger period of time. In Barway et al (2011), they find that bar fraction in S0 galaxies is also a function of luminosity. In all these studies, environment, i.e., whether a galaxy is isolated or lives in a group/cluster, also plays an important role.

If it is indeed true that the formation mechanisms of bright and faint S0 galaxies are different, this difference should be reflected in the star formation histories as well. The signatures of the star formation history can be found in the spectral energy distribution of these galaxies. As a part of this thesis, we have used multi-wavelength data from ultravoilet through mid-infrared from surveys such as the Galaxy Evolution Explorer (GALEX), the Sloan Digital Sky Survey (SDSS), the Two Micron All Sky Survey (2MASS) and the Wide-field Infrared Survey Explorer (WISE) to check the luminosity dependence of star formation histories. The sample of galaxies used for the study is derived from the Uppsala General Catalog (UGC). We use various diagnostics such as the $FUV - NUV$ vs $NUV - K$ colour-colour diagram, the $NUV - r$ colour and the $D_n(4000)$ index to compare the stellar populations as a function of luminosity and environment. We find that indeed bright S0 galaxies are consistent with a single coeval population of stars with age $\sim 10^{9-10}$ years. The faint S0s, however, have a more complicated star formation history. The environment is found to have a secondary effect.

While in the first part of the thesis, the properties studied are of galaxies taken as a whole, the second part of the thesis focusses on individual properties of the bulges and disks. In particular, the dichotomy of bulges in the context of S0 galaxies are studied. By this, we refer to the known existence of at least two types of bulges - the classical bulges, which can be viewed as ellipticals surrounded by a disk (Renzini 1999), and the pseudo-bulges, which are currently understood to be inner disk-like components formed through secular evolution (Kormendy and Kennicutt 2004). For this study, the surface brightness profiles of a sample of S0s and spirals, as captured in the 3.6 micron imaging provided by the Spitzer Space Telescope's Infrared Array Camera, are decomposed into the bulge, disk (and bar) components using the technique of 2-d image decomposition. The properties of the bulges are used to classify them on the basis of criteria established in literature by, for example, (Fisher and Drory 2008) and (Gadotti 2009). However, the data obtained by the Spitzer Space Telescope requires significant amount of preprocessing before the standard technique of 2-d image decomposition can be employed. Before presenting the results based on the obtained structural parameters, the thesis covers in great detail the steps needed for this preprocessing and their importance.

A comparison of the disk properties of classical and pseudo-bulge hosting S0s reveals differences depending on the type of bulge hosted. In particular, the scale length of the disk is on average smaller for pseudo-bulge hosting S0s compared to that of classical bulge hosting S0s. The S0s hosting these two types of bulges are also found to obey an offset relation between the central surface brightness of the disk and its scale length. Pseudo-bulges evolve through secular processes in which the disk gas and stellar matter fall inwards as a result of instabilities within the disk, like a bar for example, leading to the formation of an inner disk like component. One can interpret the differences in the disk properties as signatures of the process that lead to the formation of the pseudo-bulges. An alternate interpretation can also be that there is a bimodality of disks in the Universe and at least for S0 galaxies, disks with lower scale length have a higher probability of hosting pseudo-bulges.

Another possible hypothesis to explain the differences in the disk properties of pseudo-bulge hosting S0s is that they are a signature of the processes responsible for transforming the spiral galaxiess into S0s. For example, if a spiral galaxy is subjected to gas stripping, it will extinguish the star formation leading to the fading of spiral arms. This will cause the spiral to transform and appear like an S0 galaxy. In order to verify if this is possible, we compare our sample of pseudo-bulge hosting S0 galaxies with a sample of pseudo-bulge hosting spiral galaxies. We find that among them, the early-type galaxies are consistent with being the progenitors of pseudo-bulge hosting S0s in the gas stripping scenario, while the late-type galaxies cannot transform into present day pseudo-bulge hosting S0s in the same manner unless aided by additional processes such as accretion of dwarf galaxies through minor mergers.

The first two parts of the thesis are statistical studies carried out using detailed analysis of imaging data for various samples of S0 galaxies. However, a true understanding of the formation history and properties of S0 galaxies requires detailed modelling and analysis of their spectrum. In the third part of the thesis, we review the methods by which longslit spectra of the galaxies can be used to comment on

their properties and describe an ongoing project with the Southern African Large Telescope (SALT). The thesis describes the pipelines developed for the basic data reduction, the determination of rotation curves and the modelling of spectra using Starlight (Cid Fernandes et al. 2005). Preliminary results for a subset of galaxies in the form of age gradients, change in population abundances as a function of the position along the major axis of the galaxy are presented. The consistency of the results with currently accepted formation mechanisms for these objects is discussed.

The thesis concludes with a summary of all the studies and a description of the potential work that can be done to further the understanding of S0 galaxies and galaxies in general.

THE ASTROSAT

India's astronomy satellite, AstroSat was launched on September 28, 2015 from Satish Dhawan Space Centre, Sriharikota. This marked the culmination of many years of effort of several scientific institutions in India, including IUCAA. AstroSat is built to observe the sky simultaneously in a wide range of electromagnetic spectrum, using five major science payloads on board: Cadmium Zinc Telluride Imager (CZTI), Ultra Violet Imaging Telescope (UVIT), Large Area X-ray Proportional Counter (LAXPC), Soft X-ray Telescope (SXT), and Scanning Sky Monitor (SSM).

Fig. 1: A view of the AstroSat launch

Scientists at IUCAA have been involved in many aspects of the AstroSat mission. Shyam N. Tandon of IUCAA has led the construction of the UVIT. A team led by Dipankar Bhattacharya has set up the Payload Operation Centre of the CZTI at IUCAA, and has been running it since. He has also been involved in several other activities of mission planning and operations, as well as in the development of data analysis algorithms and software for CZTI and SSM. Gulab C. Dewangan has led the development, maintenance and enhancement of the AstroSat Proposal Processing System software package, which has become an indispensable cornerstone of AstroSat mission operations. He has also contributed to the data analysis software of the SXT. Ranjeev Misra and Mayukh Pahari have made valuable contributions to the data analysis activity of the LAXPC. R. Srianand and Kanak Saha have helped to plan and carry out observations with the UVIT.

CADMIUM ZINC TELLURIDE IMAGER (CZTI) PAYLOAD OPERATIONS CENTRE (POC)

The Payload Operations Centre for the Cadmium Zinc Telluride Imager was established at IUCAA through a MoU with TIFR, Mumbai, the PI institution. The responsibility of the POC is to monitor and manage the health of the payload and process the raw data received from the payload into scientifically useful products. These activities are to be carried out on a continuous basis through the entire life of the mission.

In the months leading to the launch of POC witnessed intense activity, obtaining and processing ground calibration data of the payload in preparation for post-launch data analysis tasks. Each of the sixteen thousand pixels of the detector was individually calibrated at multiple temperatures and multiple incident energies, and detailed response profile was compiled for each of them. These responses were then integrated into the data pipeline software developed for generating science products.

Fig. 2: The fully assembled CZT Imager payload

After launch, the CZTI was the first science payload to be switched on. Following a few days of configuration, stabilization and tests, astronomical observations were initiated on October 6, 2015, starting with that of the Crab Nebula and its pulsar. The first light observation of AstroSat was thus obtained by the CZTI. The data were processed at the POC and the first light image was generated (shown below).

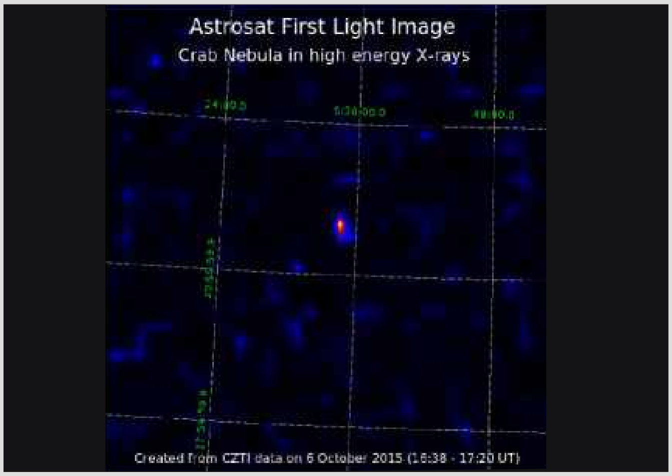


Fig. 3: The first light image of the CZTI and AstroSat: Crab Nebula, October 6, 2015

Observations carried out over the first six months of the mission were devoted to in-flight calibration of the mission and its payloads. From CZTI observations, timing analysis of the Crab Pulsar, which is a fast spinning neutron star embedded within the Crab Nebula, was carried out. The pulsar was detected strongly and its spin rate was determined accurately enough to detect with very high significance in its spin-down (lengthening of spin period) by as little as 18 nano-second in the course of one day.

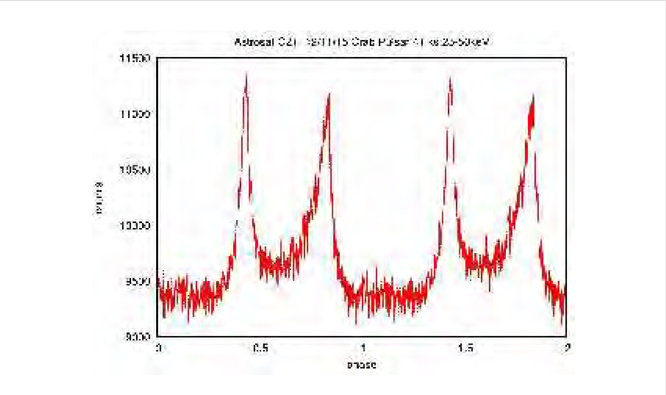


Fig. 4: The pulse profile of the Crab Pulsar observed with the AstroSat CZTI

Serendipitously, within a few hours of the start of operation, the CZTI detected a Gamma Ray Burst, GRB151006A. GRBs are the most intense outbursts of high energy emission in the universe, and they signal the birth of black holes. The CZTI has proved to be very capable in the detection of these events, from practically anywhere in the sky. GRB151006A occurred nearly 60 deg away from the main field of view. Till the end of March 2016, almost 20 GRBs has been recorded in the CZTI, of which only one, GRB160325A, occurred within the main field of view of the instrument. In addition, CZTI has the capability to detect hard X-ray polarization of bright sources via spatial distribution of Compton scattered double events in the detector. GRB151006A, and later GRB160131A have showed evidence of strong linear polarization of order 40 - 60 % in the CZTI Compton band of 100 – 250 keV. Further analysis of this is in progress.

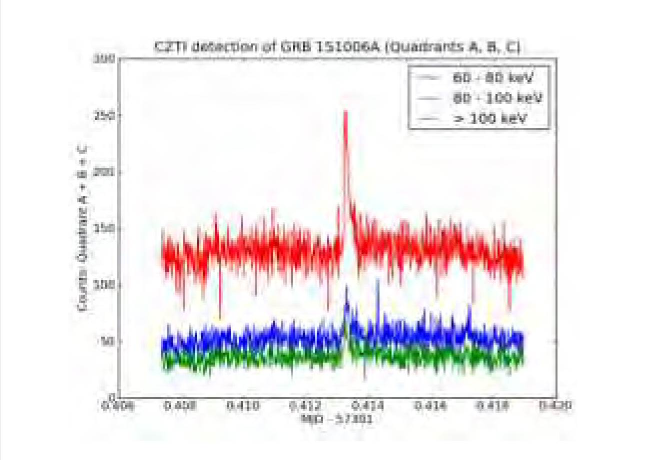


Fig. 5: The first Gamma Ray Burst detected by the AstroSat CZTI

Ever since the first day of operation, the CZTI POC has been routinely receiving data from the Indian Space Science Data Centre (ISSDC), Bengaluru, after every download pass. Initially, the received data volume was nearly an order of magnitude larger than expected, as the background events due to charged particle interactions turned out to be much more numerous than anticipated. In February 2016, the on-board processor of the CZTI was re-programmed to recognise and filter these additional events. Since then, the rate of raw data received is about 5 GB/day, in ~15 orbits. A robust and automated analysis pipeline has been developed and deployed at the POC, which converts this raw data to science products that are sent back to the ISSDC. Analysis of this data is also being carried out to continuously monitor the health of the payload, as well as to track changes in calibration, if any. In addition, a regular search for GRB detections is being performed on the data.

ULTRA VIOLET IMAGING TELESCOPE (UVIT)

UVIT was designed to make images with a resolution of < 1.8", simultaneously in three channels: Far Ultraviolet (1300 - 1800 A), Near Ultraviolet (2000 - 3000 A), and Visible (3200 - 5500 A); the total field of view is ~ 28'. It was developed through a collaboration of several Indian institutions: IIA, ISRO, IUCAA, and TIFR, and Canadian Space Agency. UVIT is performing well in the orbit, and is expected to produce a large volume of excellent astronomical results over its life of 5 years. A quick view of its performance in the orbit is presented below.

Fig. 6: UVIT on vibration test bed before launch

In order to minimise any possible contaminations from the other payloads, etc. on the satellite, the doors of UVIT were only opened 2 months after the launch. After openings of the doors, observations were made for 4 months for calibrations. Results of the calibrations show a high performance. Some key indicators of the performance are: (a) Sensitivity in 1300 - 1800 A is ~ 80 % of what was predicted, i.e., instrumental zero-point is AB-mag. 18.08 (this gives one detected photon per second), (b) The point spread function gives full width at half maximum of < 1.6”, (c) The background in 1300 - 1800 A for dark fields is ~ AB mag. 26 for 10 square arcsecond solid angle, and (d) Mean relative astro-metric accuracy within the field for the Near Ultraviolet detector is found to be < 0.5”, which suggests bright prospects for deep imaging in which coincidences are to be found with objects seen in other images, e.g., images from ground based observations.

Figure 7 illustrates the spatial resolution of UVIT in Near Ultraviolet. For comparison, image of the same source by Galex (a satellite devoted to imaging in ultraviolet with a wide field of 1.2 deg.) is also shown in Figure 8. The much higher (by ~ 3) spatial resolution of the UVIT-image is apparent.

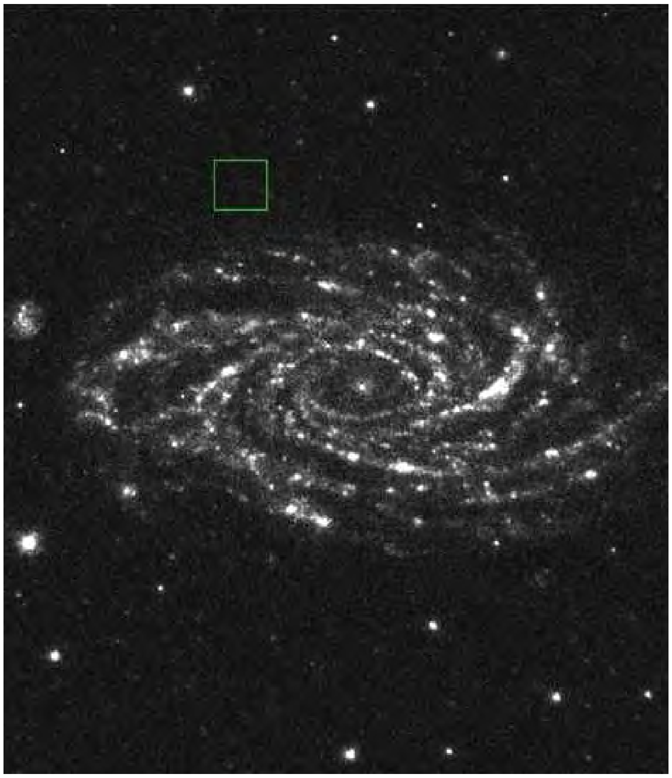


Fig. 7: Image of galaxy NGC2336 taken with Galex in Near Ultraviolet

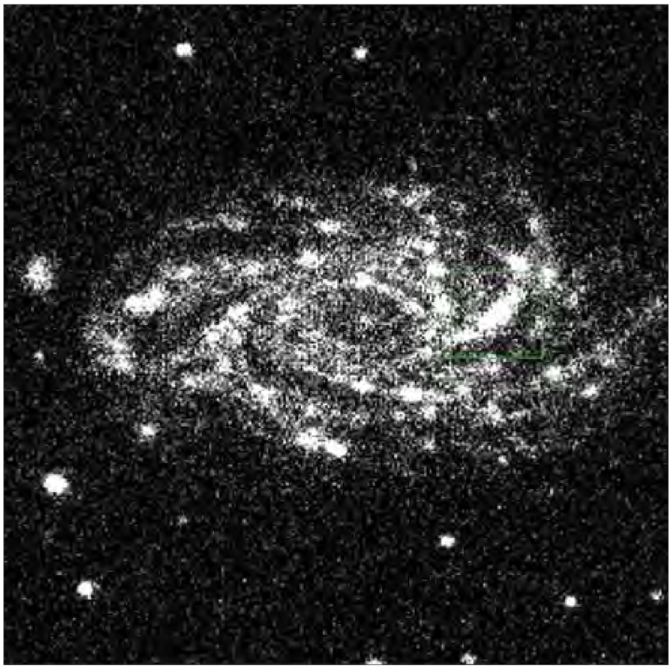


Fig. 8: Image of galaxy NGC2336 taken with Galex in Near Ultraviolet

Science observations have just started with UVIT and there are bright prospects for exciting results on a large variety of objects, from individual stars to clusters of galaxies in sizes, including multi-wavelength observations of temporal variations in coordination with the X-ray telescopes on Astro Sat.

LARGE AREA X-RAY PROPORTIONAL COUNTER (LAXPC)

The primary objective of this instrument is to study the variability of X-ray binaries. X-ray binaries consist of a normal star and a compact object such as a neutron star or black hole, and matter from the normal star accretes on to the compact object giving out copious amount of X-ray. They are variable in a wide range of time-scales, and this variability, especially the rapid one, provides important clues on the behaviour of matter in strong gravity, where spacetime is curved according to Einstein's General Theory of Relativity. Like the earlier US satellite, the Rossi X-ray Timing Explorer (RXTE), which has been de-commissioned now, LAXPC is the only instrument which can measure the variability of X-ray binaries in milli-second time-scales. More importantly, the larger effective area of LAXPC at high X-ray energies compared to RXTE is expected to provide an unprecedented view of the high energy X-ray variability of these sources.

However, quantifying such rapid variability from the data is a daunting task, where several instrumental effects have to be taken into account. Moreover, such analysis which involves a large number of Fourier transforms to be undertaken, requires efficient software that can reveal intrinsic features of the data. Ranjeev Misra and Mayukh Pahari are members of the LAXPC science team and have been working on writing such computer codes, which consider correctly all the instrumental effects in an efficient manner. They have developed and tested codes which can generate the power spectrum for a wide range of frequencies, correlate the photon arrival times between different energy bands, hence measuring time-delays between them, which may be as short as tens of micro-seconds and provide information about the spectrum as a function of the variable flux level. For example, the electronics of the LAXPC has a deadtime of around 50 micro-seconds, which means that after an X-ray photon is detected, the system does not register any other photon during the deadtime. This causes spurious effects which have to be understood before real signals can be deciphered. For the power spectrum which is a measure of variability at different time-scales, deadtime effect can change the expected variation due to Poisson (or photon counting) fluctuations. Figure 9 shows the power spectrum computed for a X-ray binary observed by LAXPC using software developed at IUCAA. This source is not supposed to show significant high frequency variability and the variation is only due to Poisson noise, affected by deadtime. As shown in the figure, the modelled deadtime effect (blue dotted line) matches well with power spectrum obtained, giving confidence that LAXPC can indeed observe milli-second or shorter time scale variability, and hence will be a more advanced successor of the RXTE legacy.

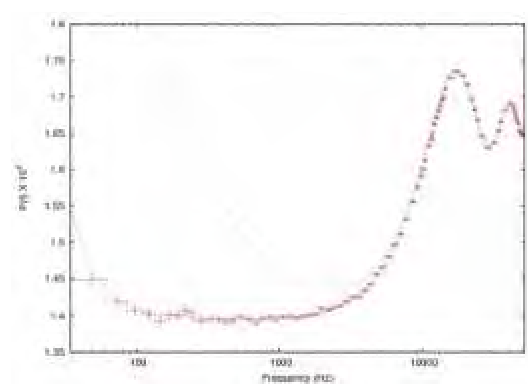


Fig. 9: Power density spectrum of intensity fluctuations from an X-ray binary observed by LAXPC

ASTROSAT PROPOSAL PROCESSING SYSTEM (APPS)

AstroSat is a multi-wavelength astrophysics observatory for a large scientific community. Effective operation of a space observatory such as AstroSat leading to major scientific advancement is a complex process. The five payloads onboard AstroSat have different scientific capabilities and technical constraints. The peer-reviewed, scientific proposal-driven operation of AstroSat is intricate and challenging. To facilitate the proposal-driven operation of the AstroSat mission, a web-based proposal processing software known as the "AstroSat Proposal Processing System (APPS)" has been designed and developed by IUCAA in collaboration with Persistent Systems Limited (PSL), Pune. APPS is available to the scientific community for preparation and submission of AstroSat proposals and to the mission operation to extract the proposals database for scheduling of observation and command generation to perform the actual observations. The role of APPS in the proposal-driven operation of AstroSat mission is depicted in Figure 10.

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

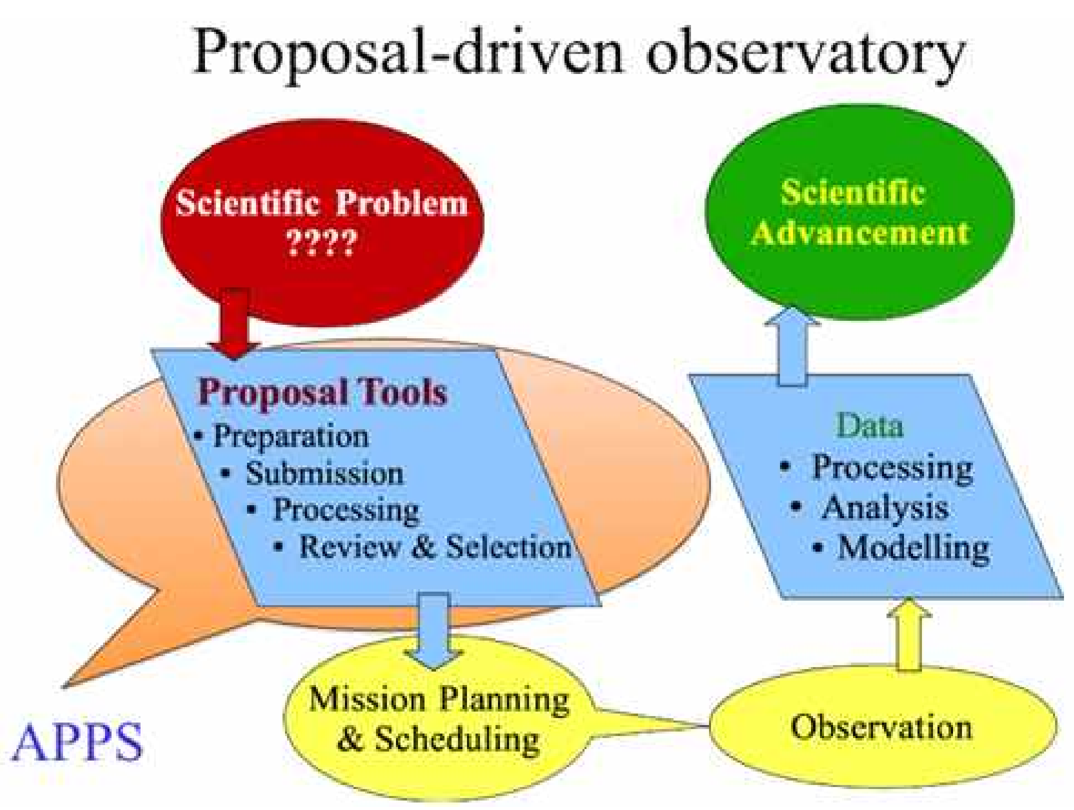


Fig.10: Proposal driven operation of AstroSat and the role of APPS software.

An overview of the APPS architecture along with the flow of various kinds of information into and out of the APPS can be seen in the following flow diagram shown in Figure 11.

played crucial role in quick addition of new features as per the requirement, documentation, bug fixing and feature enhancement. IUCAA has also provided time-critical support to

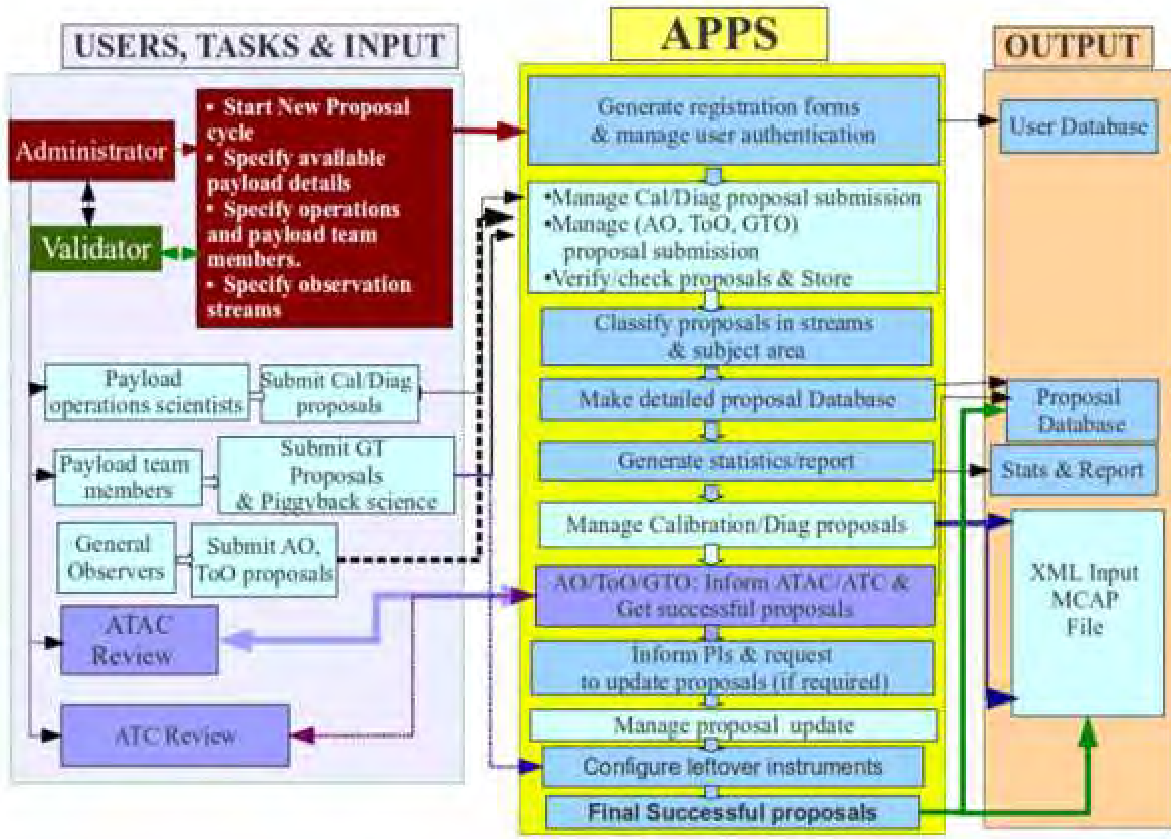


Fig. 11: Schematic representation of APPS software.

APPS is currently deployed at Indian Space Science Data Centre (ISSDC), ISRO, Bengaluru. While the software is made available from ISSDC, IUCAA has been providing administrative, operational, maintenance and enhancement support continuously. IUCAA also plays a key role in providing support to the user community in proposal preparation and submission using APPS.

APPS has been successfully used for proposal preparation, submission and selection for observations in the performance verification (PV) and the guaranteed time (GT) phase in the first year of AstroSat mission. During this period, IUCAA has administrative activities including proposal cycle creation, setting instrument configuration, handling proposal review during the GT cycle and revision of proposals, verifying and fixing issues with the mission control and proposals database (MCAP), which is used for mission planning, scheduling of observation and command generation. IUCAA has also provided support to the proposers from instrument teams for submission of PV and GT proposals.

ASTROSAT TIME ALLOCATION COMMITTEE (ATAC)

The AstroSat Time Allocation Committee (ATAC) has been set up by ISRO to review the AstroSat GT and AO proposals. With the involvement in the development and maintenance of APPS software and two members of IUCAA faculty as members of ATAC, IUCAA plays a significant role in the review, revision, selection process and interfaces with the mission operation team at ISRO to ensure smooth flow of proposals data from APPS to the mission operation in the form of Mission Control and Proposals database (MCAP), which is then used for scheduling of observations and command generation for actual observations.

COMPUTING FACILITY

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

The hardware and devices currently managed by the computing facility include 300 servers and desktops, 70 laptop computers, 60 printers and scanners, two large High Performance Computing systems and over a PetaByte of storage, in addition to diverse equipments deployed for an extensive, high throughput wired and wireless campus-wide network. The number of registered users of these facilities is over 170, and e-mail accounts served by the computing facility amount to nearly 500.

In the year 2015-16, the main thrust was given to (i) Creating an exclusive High Througput Computing (HTC) of 40 TF environment, and (ii) Expanding the Data Centre infrastructure to accommodate the HTC for the Gravitational Wave group.

In August 2015, the email addresses of IUCAA staff members were migrated to IUCAA owned domain iucaa.in from ERNET owned domain iucaa.ernet.in, thus withdrawing its dependency on the ISP (Internet Service Provider) ERNET. Similar migration of email addresses for Visiting Associates of IUCAA from associates.iucaa.ernet.in to associates.iucaa.in, too was scheduled for a later date.

IUCAA had been utilizing the National Knowledge Network (NKN) as the primary ISP and ERNET (Educational and Research NETwork) as the secondary ISP till September 2015 for their internet usage. The WAN link bandwidth provided by NKN and ERNET amounted to 1 Gbps and 20 Mbps respectively. These two independent link paths were configured to provide redundancy and robustness to the WAN connectivity. When the ERNET link started to ride over NKN, this redundancy was lost. Therefore, an alternative ISP TATA Communication was identified to offer a 50 Mbps link, which has been deployed for use by IUCAA since October 2015.

The Computer Centre continues to impart technical support to visitors, project students, IUCAA associates as well as visitors from the universities and institutions within India and abroad. The Computing Facility employs 8 personnel, who carry out the day-to-day functions that include:

1. Architecting overall IT solution/technologies required for IUCAA, and present it to Computer Users' committee for their consensus.
2. Framing policy documents and finalizing them in consultation with the Computer Users' committee members.
3. Drawing up specification for the RFP (Request for Proposal) tender document for IUCAA IT requirement to be purchased and oversee all purchase related procedure and follow up.
4. Maintenance of IT hardware in the campus including servers, desktops, mobile computing equipment, printers, etc.
5. Maintaining Zimbra email servers and their day-to-day administration.
6. Configuration and maintenance of mirror sites hosted at IUCAA.
7. Configuration and management of data backups.
8. Design, management and administration of network topology and firewall rules.

9. Administration of Ruckus wireless network covering the office as well as residential campus.

10. Configuration of WiFi support to devices such as laptops, mobile devices for end users

11. Day to day administration of VmWare infrastructure and various servers catering to Administration such as AD, etc.

12. Maintenance of Video Conferencing equipment and end user support.

13. Comprehensive inventory management and tracking.

14. Procurement of SSL certificates and software for all the relevant web servers at IUCAA.

15. Management and software development for iOAS (integrated Office Automation System), Tally, and TDS pack.

16. Designing web portals for various online applications.

17. End user service support to Administrative Staff, Academic Members, Visitors and Associates.

18. Infrastructure, management and coding support to IT intensive projects such as Virtual Observatory, AstroSat, LIGO, etc.

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

20. Hardware maintenance and General System Administration of clusters in IUCAA in co-ordination with OEM.

21. Assisting Estate Department with Data Centre management.

HIGH PERFORMANCE COMPUTING

The High Performance Computing Facility houses some of the major IT assets of IUCAA. During 2015-16, two old cluster computing systems, "Cetus" and "Pleiades", were de-commissioned and the HPC services were consolidated into the new 1504-core 30 Teraflop

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

HPC system “Perseus”, which also has a 750 Terabyte storage attached to it. One-third of this HPC has been configured into a Condor-based High Throughput Computing system dedicated to Gravitational Wave data analysis. The remaining has been available for general use with LSF (Load Sharing Facility) as the job scheduler. This 1024-core partition of the HPC was utilized by more than 25 high volume users from IUCAA and various Indian universities, running applications for Molecular Scattering, Molecular Dynamics, Stellar Dynamics, Gravitational N-body Simulations, Cosmic Microwave Backgound Evolution, Fluid Mechanics, Magneto-hydrodynamics, Plasma Physics and the analysis of diverse astronomical data. One major data analysis application has been to generate complete optical light curves of 350 million astronomical sources observed in the Catalina Real-time Transient Survey (CRTS), by going through the entire repository of images collected over the years.

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

IUCAA High Performance Computing clusters Perseus (left two racks) and Sarathi

Chiller plant assembly for IUCAA Data Centre

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

IUCAA GIRAWALI OBSERVATORY

The 2m optical telescope at IUCAA Girawali Observatory (IGO) is currently undergoing refurbishment to upgrade its hardware and software, which requires a total revamp, and the process to get this completed is initiated with the industrial vendors. Attempts are also made to install an Adaptive Optics module in near future to obtain limited observations. In addition, to the existing IFOCS instrument, a side port Fabry-Perot imaging spectrograph fabrication is also underway.

An additional small building has been completed adjacent to the present service building of IGO. It is planned to place 2 small automated telescopes (upto 0.5meter) for ground based optical follow-ups of various transient events. This new building has a provision for one night observer's stay and an additional guest room and office space etc. A view of this new building is attached

THE SOUTHERN AFRICAN LARGE TELESCOPE

The Southern African Large Telescope (SALT) is the largest single optical telescope in the southern hemisphere, and amongst the largest in the world. It has a hexagonal primary mirror array 11 m across, comprising 91 individual 1 m hexagonal mirrors. It is the non-identical twin of the Hobby - Eberly Telescope (HET), located at McDonald Observatory, Texas, USA. HET and SALT represent a completely new paradigm in the design of optical telescopes.

SALT is owned by the SALT Foundation, a private company registered in South Africa. The shareholders of this company include universities, institutions and science funding agencies from Africa, India, Europe, New Zealand and North America. The South African National Research Foundation is the major shareholder with ~1/3 stake. Other large shareholders are Dartmouth College, University of Wisconsin-Madison, Rutgers University (all in USA), and Nicolaus Copernicus Astronomical Centre of the Polish Academy of Sciences. Smaller shareholders include the American Museum of Natural History (USA), Inter-University Centre for Astronomy and Astrophysics (India), University of Canterbury (New Zealand), University of North Carolina (USA), University of Gottingen (Germany), and the UK SALT Consortium, the latter representing the Universities of Central Lancashire, Keele, Nottingham and Southampton, and the Open University, and the Armagh Observatory. The size of the shareholding of each partner determines the access to use the telescope. IUCAA share amounts to about 6.5% of the total distributed share. For the past year, this corresponds to an observing time of 600 ks (~ 21 nights).

The time allocation in IUCAA is done through a committee, consists of R. Srianand (Chair), Dipankar Bhattacharya and A. N. Ramaprakash. Typically, IUCAA time of the SALT is over subscribed by 1.2 to 1.5 times. This means all the available observing time is well utilised.

About 45% of IUCAA observing time has been utilised for target selection for the upcoming MeerKAT Absorption Line Survey (MALS) (PIs: Neeraj Gupta and R. Srianand, both from IUCAA). The MALS is one of the ten large surveys to be carried out with the MeerKAT Radio Telescope in South Africa. The main objective is to carry out a sensitive blind search for HI 21 cm and OH absorption lines, and trace the evolution of cold atomic and molecular gas in galaxies at $z < 1.5$. A dust-unbiased sample of bright (> 200 mJy at 1 GHz) radio loud quasars (RLQs) at $z > 1.5$ is required to achieve this, and build a comprehensive picture of high-z interstellar medium and its relationship with the ongoing star formation in the host galaxies. Researchers from IUCAA (Co-Is: Dipankar Bhattacharya, Rajeshwari Dutta, Tanvir Hussain and Ajit Kembhavi), with those at institutes in South Africa and Rutgers, have been carrying out an ambitious spectroscopic campaign at optical wavelengths with SALT to build the first, large, purely infra-red selected sample of RLQs at $z > 1.5$, that will be well-suited for MALS, and also address various fundamental issues related to the initial phases of AGN evolution. As part of this campaign, the team has been observing a sample 300 RLQs. The sample is purely selected on the basis of WISE IR colours, i.e., dust unbiased. To date, they have observed about 150 high-z new RLQs.

The scientific programmes carried out using SALT during the period includes: (a) Eccentricity and orbit of 4U1700-37 by Varun Bhalerao, (b) Long exposure fast photometry of LMXB pulsar 4U1626-67 by Dipankar Bhattacharya, (c) Fuelling and feedback in the vicinity of black holes by Arunima Banerjee, (d) Variability of CaII K and NaI D lines in the direction of Vela Supernova Remnant by Ranjan Gupta, (e) Investigating the CIV BAL emergence/disappearance phenomena in a sample of BAL QSOs by R. Srianand, (f) Probing the host galaxies of ultra-strong MgII absorption line systems by Rajeshwari Dutta, and (g) High resolution spectroscopy to resolve outflows due to large accretion in FUOrs (Part 1) by Ninan Sajeeth Philip (Visiting Associate of IUCAA from St. Thomas College, Kozhencherri, Kerala). Typically 70 - 80% of the requested data through queue-scheduling have been delivered. Most of the programmes use the long-slit spectroscopic capabilities of Robert-Stobie spectrograph and high speed photometric mode of SALTICAM. Two programmes also used the recently commissioned high resolution spectrograph.

LIBRARY

During the period under review, the library added 101 books, 473 ebooks, taking the total collection to 26023. The library subscribes in print and online to 126 journals and additionally, receives access to approximately 3678 online journals courtesy INFLIBNET through the UGC-INFONET program comprising e-journals published by Institute of Physics (46), American Physical Society (13), Springer Link (1452), American Institute of Physics (19), Emerald/Emerald Publishing (30 titles), Taylor and Francis (1079) and Science Direct (1036) with three databases : Web of Science, ISID, and JCCC.

The details of various activities undertaken by the library during this period are described below.

1. The IUCAA library acquired Springer e-book collection in Physics and Astronomy for the copyright year 2015. Acquired 93 ebooks published by Elsevier.

2. The library received and fulfilled 335 full-text article requests from 180 academics (including students) through email/post/personal visits and interlibrary loan requests.

3. Full-text access to the presentations delivered during various schools and conferences held in the institute, posters displayed during the National Science Day, IUCAA Academic calendar, faculty research papers, newspaper clippings and IUCAA Preprints are available through the IUCAA Institutional Repository using DSpace latest version with new upgraded server accessible at (http://repository.iucaa.in:8080/jspui/).

4. Access to recorded lectures delivered by Professor T. Padmanabhan, Leelavati lecture series and the IUCAA Foundation Day lecture is available through IUCAA Library YouTube Channel - (https://www.youtube.com/user/iucaalib)

RADIO PHYSICS LABORATORY

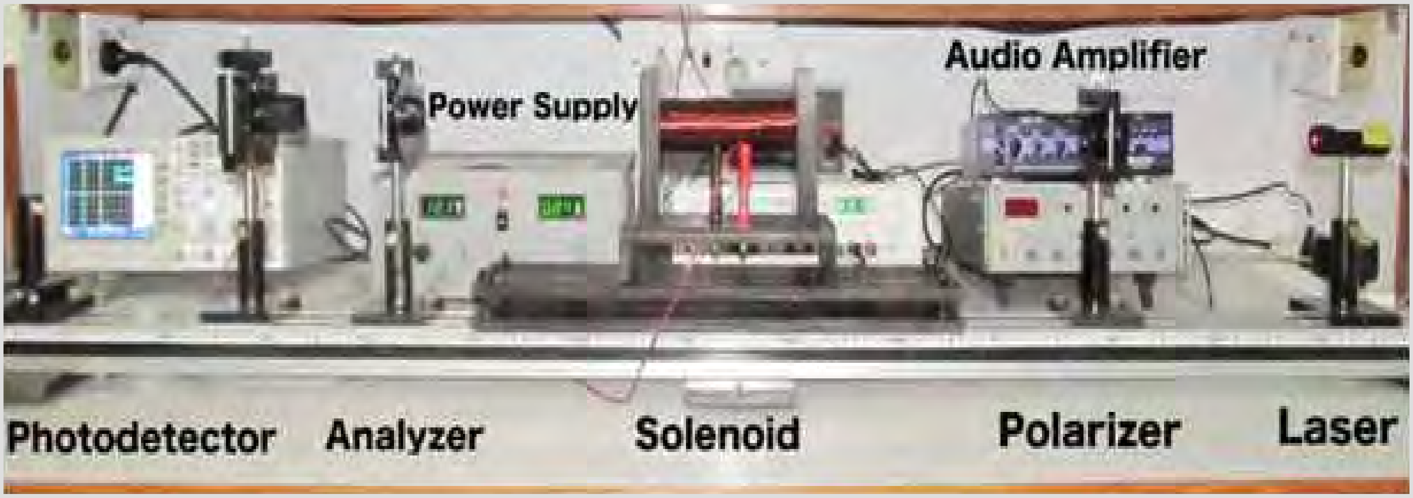
Radio Physics Lab (RPL) is active in experimental areas in astronomy, physics and engineering. Our aim has been to design and demonstrate important experiments related to astronomy in an innovative way, either for scientific purposes or for educating students, enthusiasts and general public. The areas being pursued range from cosmic ray detection to communication using LASERs. Apart from this, RPL is also active in public outreach. Public lectures and demonstrations are organized for students and enthusiasts. Radio Astronomy Winter School has been conducted for under-graduate students to introduce them to the field of radio astronomy. Over the past 10 years several students have benefited from this platform. More than 90 percent of students have gone on to do Ph.D. in astronomy and related areas, and many are currently active in research field in some form or other. Following are the details of experiments and activities carried out by RPL:

Experiments

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. In physics and optics, the polarization of light is studied through ”Faraday Rotation Effect” using optical materials like glass, crystals, chemicals, etc. Its analogue in radio waves is transmission of polarized wave in ferrites materials. The idea is to study the potential of fast polarization modulation for data communication, which is not much explored yet.

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



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

Horn Antenna for 21 cm Hydrogen Line

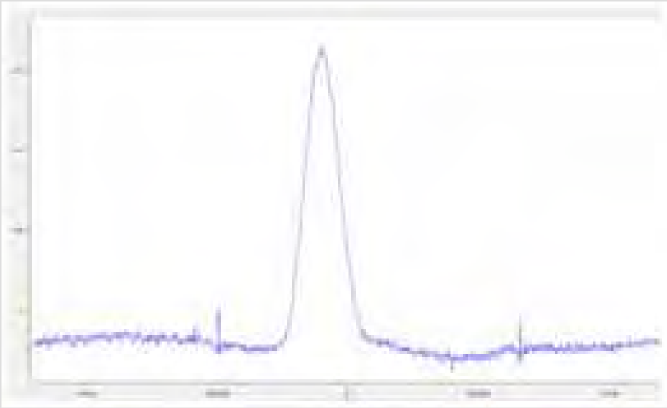
The 21 cm hydrogen line is a spectral line emitted by atomic hydrogen. Since hydrogen is the most abundant element in the universe, this makes the hydrogen line very important in radio astronomy. A horn antenna was designed for detecting this line from our galaxy. A major limitation of radio astronomy is noise, either man-made or naturally occurring. Hence, we require new techniques to reduce noise from our detector. The horn antenna is a high performance, high gain and low noise antenna, specially designed for detection of 21 cm hydrogen line. The antenna is able to pick up radiation from the hydrogen clouds in our galaxy, while suppressing terrestrial interferences due to the low side lobes of the antenna. The antenna is easy to handle and is superior to a parabolic dish in terms of noise performance.

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

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

Noise Fundamental Experiment

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



Cosmic Ray Muon Detector

The cosmic ray muon detector (CRMD) can detect and observe 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 kinds, and was built in 2011 by B.Sc. level students. It is the only detector of its type running in entire Asia. The material to build the detector was imported from Fermi Lab (USA).

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

Other Experiments

Many small experiments have been done in the lab, such as noise figure measurement of radio frequency (RF) amplifiers, and other RF components are essential for radio astronomy. This experiment has been successful in measuring noise contributed by various RF components. Solar observations are taken at 10 GHz with a satellite TV dish antenna. This is a low cost and easily available radio telescope. This experiment was designed so that even lay members can build and operate a small radio telescope made from household material. Antenna radiation pattern measurement is a fundamental experiment in understanding how an antenna works. We have a set up consisting of many types of antennas. We can study the radiation characteristics of these antennas.

Science Day

Science day is an important event in IUCAA. It is the time of the year when IUCAA is open to general public all day along, and all the staff of IUCAA is involved in activities related to public outreach. The RPL has been demonstrating and explaining various astronomy related experiments over the years. This year on February 28, 2016, we presented the horn antenna designed for detection of atomic hydrogen in our galaxy at 21 cm wavelength. A quite similar antenna was used to discover the Cosmic Microwave Background radiation by Penzias and Wilson back in 1960s. The antenna came in handy to explain how radio telescopes work, and people could actually see their applications. We also demonstrated various antennas that are used in astronomy as well as for communication.

Public Outreach

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

We also have initiated the process of making videos for general public, which will 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 telescope). All these material will be freely available on our RPL website (http://www.iucaa.in/~rpl) and Youtube channel. RPL has also launched pages on the social media like Facebook, Twitter, and Youtube for propagation of radio astronomy in India.

Paper Presentation

A paper titled "Polarization Modulation for Communication" was presented at the Second International Conference on Information Engineering, Management and Security, held at IIT - Madras, Chennai campus in August 2015.

Project Competition

A project competition was organised by the IEEE Pune Chapter to all M.E./M.Tech. students of Savitribai Phule Pune University. Jameer Manur (IUCAA) stood first in the IEEE COMSOC PG-Project Competition - 2015.

M.Sc. Practicals

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

Radio Astronomy Winter School

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

INSTRUMENTATION LABORATORY

The second version of the very successful Robo-AO instrument (http://instru.iucaa.in/index.php/projects/ongoing-projects/16-ongoing-projects/9-robo-ao) has achieved closed loop control in the lab. Once the lab tests are completed, the instrument will be installed on the IUCAA Girawali 2 m telescope. Figure 12 shows an image of the UV laser being propagated from the telescope enclosure during one of the night time tests. The first version of Robo-AO (currently deployed at the Kitt Peak 2 m telescope) had only a visible arm for science observations. An infrared arm (see Figure 13) has been developed at IUCAA for the Robo-AO system and is undergoing final tests.

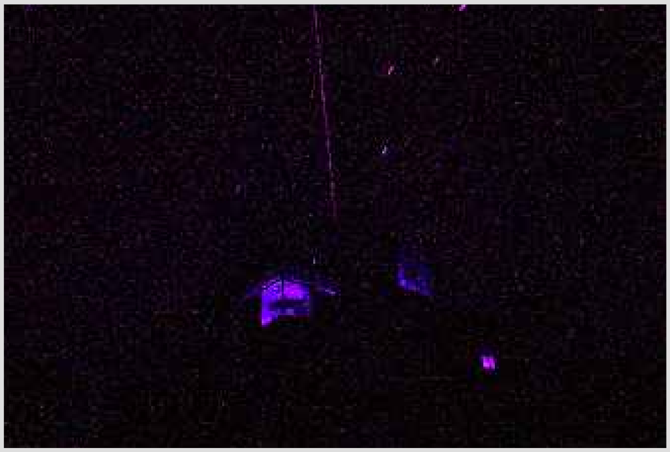


Fig. 12: Laser beam being propagated for atmospheric wavefront sensing from enclosure of the IUCAA Girawali 2 m telescope.

Fig. 13: The infrared science and tip/tilt sensor arm for Robo-AO that has been developed in the IUCAA laboratory.

Sabyasachi Chattopadhyay (IUCAA Ph.D. student), Haeun Chung (Ph.D. student of Seoul National University), and the instrumentation group are working on the design and development of Devasthal Optical Telescope Integral Field Spectrograph (DOTIFS) (see Figure 14), which is a multi-object Integral Field Spectrograph (IFS) for the Cassegrain side port of the 3.6 m Devasthal Optical Telescope (DOT). Its main scientific objectives are the physics and kinematics of the ionized gas, star formation and H II regions in nearby galaxies. The uniqueness of the instrument lies in the multi-IFU deployment system and high throughput in the wavelength range of 370 - 740 nm. Over 2,300 optical fibres are used to form 16 integral field units (IFUs), each of which is comprised of a microlens array and 144 optical fibres (see Figures 15 and 16) and has 7.4” × 8.7” field of view with 144 spaxel elements with a sampling of 0.8” hexagonal aperture. The sixteen IFUs are deployable over an 8 arcminute diameter patrol field at the telescope focal plane. The instrument consists of eight identical spectrographs, each of which produces 288 spectral traces from two IFUs. Optics and detector procurement and mechanical design are currently underway. Detector controller has been tested with a 2K x 2K detector currently available in the lab.

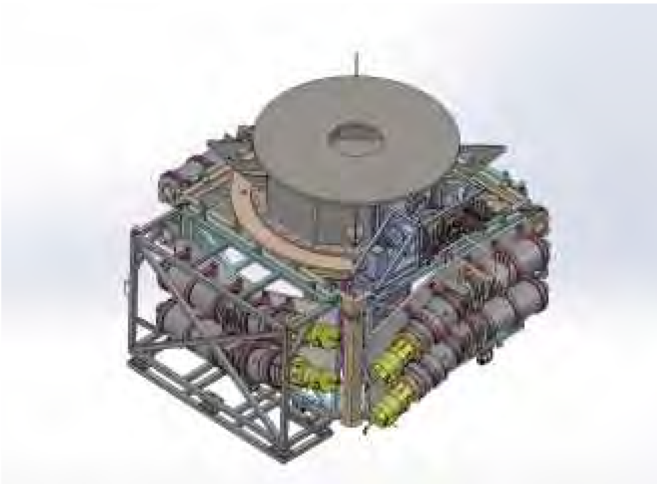


Fig. 14: Solid Works model of the DOTIFS instrument mounted on the Cassegrain sideport of the 3.6 m Devasthal Optical Telescope.

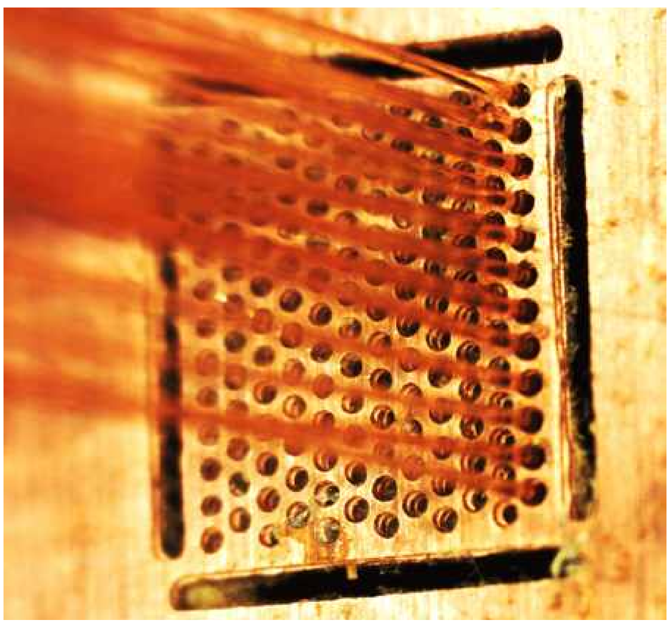


Fig. 15: An IFU being fabricated with fibres inserted into a mask array.

An IFU has been fabricated for test by using the novel approach based on photo-lithography. The algorithm for collision free deployment of the IFUs on the focal plane has also been tested.

The Solar Ultraviolet Imaging Telescope (SUIT, see Figure 17) on-board the Aditya-L1 is imaging the Sun 24 x 7 from the Lagrangian-1 (L1) point with a high spatial resolution of 0.7”/ pixel and a cadence of nearly 30 seconds within the Near-UV wavelength domain (200 - 400) nm. It provides full-disk as well as region-of-interest (ROI) specific images of the solar features, all the way from the photosphere to the lower transition region. It also works in handshake-mode with another payload of the satellite, SoLEX to study the evolution of solar flares. Another

Fig. 16: Back illuminated prototype integral field unit that was fabricated by novel photo-lithography based technique.

set of 3 comparatively broadband filters are used to study the space weather and climate. It is for the first time that any instrument will provide images of the Sun in these wavelengths from the L1 point on an uninterrupted basis with such spatial and temporal resolution.

Fig.17: Solid Works model of the Solar Ultraviolet Imaging Telescope (SUIT) on board ISRO's Aditya-L1 mission.

Durgesh Tripathi and A. N. Ramaprakash are the IUCAA faculty members leading this project. Two Ph.D. students, Avyarthana Ghosh, (from IISER, Kolkatta) and Subhamoy Chatterjee (from IIA, Bengaluru) are currently working on various aspects of the payload development. Aafaque Khan (IUCAA) is the lead engineer responsible for systems engineering. The optical design of the instrument has been completed, and the primary and secondary mirrors are being fabricated by LEOS, Bengaluru. Several other ISRO agencies (ISAC, IISU, ISITE, etc.) are involved in the design and development of different sub-systems. At present, a laboratory model of the instrument is being developed. Aditya-L1 is currently slated for a launch in late 2019 or early 2020.

IUCAA SIDECAR Drive Electronics Controller (ISDEC V2.0) is currently being integrated into the MIRADAS instrument on the 10.4 m GTC telescope on La Palma. This controller is also being used for the Large Binocular Telescope Interferometer (LBTI) through an MoU signed with the University of Arizona and LBTI Corporation. ISDEC was successfully retrofitted with new modes of operation in order to meet the requirements of the fringe tracking application for the interferometer. At present, work is in progress to develop the next version of ISDEC, which will be able to handle the very high speed (5 megapixels per second per channel over 32 channels) readout modes offered by HAWAII detectors. It will also offer the ability to interface with and control two H2RG detectors simultaneously.

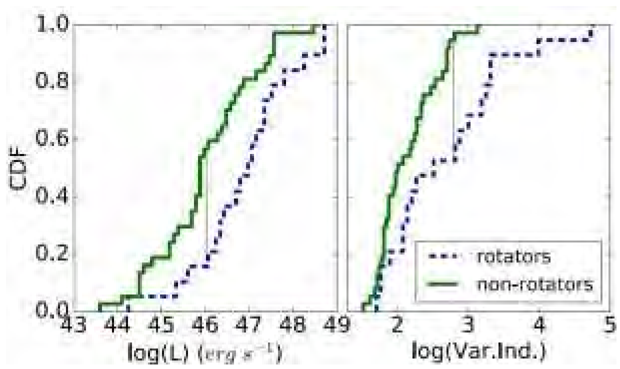


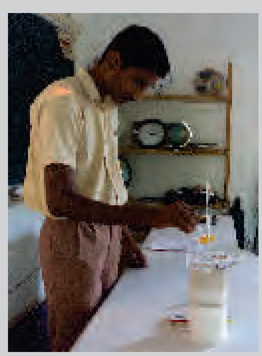
Fig. 18: Cumulative Distribution Functions (CDF) of luminosity (left) and variability index (right) for rotators and non-rotators.
The red vertical lines indicate the maximum difference between the CDFs.

The RoboPol instrument, which was designed and developed at IUCAA successfully completed the planned three year blazar monitoring campaign at the Skinakas Observatory. Over 10 publications have already appeared in journals and several more are in the pipeline. The survey covered 133 gamma-ray loud and 17 gamma-ray quiet sources, which has enabled several statistical studies (see Figure 18) of the optical polarization rotations and their association with other phenomena observed in these objects.

A new collaboration is being forged between IUCAA, Caltech USA, University of Crete Greece and SAAO South Africa to carry out an ambitious optical linear polarimetric survey of a large area of the high galactic latitude sky. Combined with accurate distance estimates from GAIA mission, the collaboration aims to create a 3D map of the galactic magnetic fields in these sky areas. The survey will be enabled by a unique instrument called Wide Area Linear Optical Polarimeter (WALOP), which is being designed and developed at IUCAA. The instrument would be based on the technique of single-shot polarimetry that was developed for RoboPol, but would work over a wide-field of 30 x 30 arcminutes. High accuracy (better than 0.03%), high sensitivity (R magnitude limit fainter than 16), and high efficiency (cover over 1,000 sq. degrees of sky) are required to meet the survey requirements. Work on the design and development of the first WALOP was kick started with a generous grant from the Infosys Foundation. This instrument will be used on a 1 m telescope in Sutherland, South Africa. Subsequently, another grant from the Niarchos Stavros Foundation in Greece has enabled the collaboration to build a second instrument, which will be installed on the Skinakas telescope.

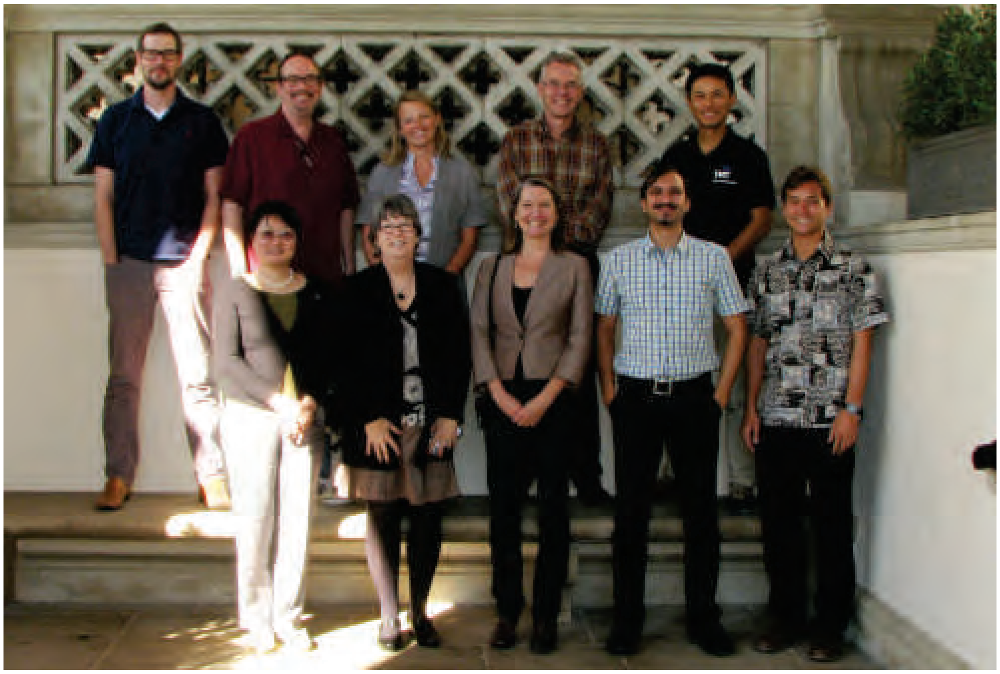
PUBLIC OUTREACH HIGHLIGHTS

SCHOOL STUDENTS' SUMMER PROGRAMME AND ASTRONOMY SUMMER CAMP



School Students' Summer Programme and Astronomy Summer Camp was conducted at IUCAA during April - May 2015. [For details see Khagol, No.103, July 2015]

TMT WEPOC ACTIVITIES



IUCAA is a partner in the Workforce, Education, Public Outreach and Communications (WEPOC) initiative of the Thirty Metre Telescope International Observatory (TIO).

Samir Dhurde presented at the TMT partners' meeting in Pasadena, USA (November 2015) and also conducted TMT related outreach during the TMT Science Workshop at Tezpur University.

TRAINING PROGRAMME IN ASTRONOMY FOR AFRICAN SCIENTISTS

A special session on conducting Astronomy Outreach was held at IUCAA Muktangan Vidnyan Science Centre.

HERE COMES THE SUN

IUCAA conducted one teachers' workshop and several students' workshops on the theme of the Sun. The content for these was developed under a collaborative project with Helen Mason, University of Cambridge, UK. Mason, Durgesh Tripathi and Samir Dhurde were the coordinators for these workshops. Revati Shinde, Kshitija Angaluri (outreach interns) and Sonal Thorve designed and conducted most activities.

Bharat Ratra.....

IUCAA organised a special public talk on 21st Century Cosmology: From Quantum Foam to the Cosmic Web by the renowned French scientist Francois Bouchet. [For details see Khagol, No. 103, July 2015]

GRAVITATIONAL WAVE DISCOVERY EVENT (FEBRUARY 2016)

The historic event was highlighted widely in the media and was shared directly with the student community and general public. The website of the gravitational wave group at IUCAA was developed for this occasion and several interesting write-ups and films were hosted on it.

Several public talks were given by the members of the gravitational wave group at IUCAA (http://gw.iucaa.in) including Sanjeev Dhurandhar.

ASTROSAT OUTREACH

Samir Dhurde was designated to be a part of the ISRO Trainings and Outreach Team and helped create a handbook as well as a set of popular level posters for the AstroSat mission.

A precise 1:4 scale model of the AstroSat was fabricated for display in exhibitions.

PUBLIC TALKS

ISRO Chairman, A. S. Kiran Kumar, gave a public talk on the topic “Space Exploration”.

AMATEUR ASTRONOMY

IUCAA MVS provided facility and training for events and serious observations to the amateur astronomy groups like Aakashmitra, Jyotirvidya Parisanstha and Khagol Vishwa

- Day time Venus occultation: Observing and webcast on May 17, 2015
- A month-long 100 sq degree sky survey for transients with IUCAA 14" telescope
- A study of light curves of 5 variable stars.
- Amateur Radio Astronomy workshop series
- Special Citizen Science Awareness survey

TARAMANDAL (MOBILE PLANETARIUM)

Several training sessions and shows were conducted at IUCAA, and in local schools and colleges.

SCIENCE TOYS ACTIVITY

The IUCCA outreach group has contributed

- 20 workshops with teachers and educators
- 80 workshops for school students
- 150 resource films

TELESCOPE MAKING WORKSHOPS

The new format reflecting telescope making workshops continued during the year with about 40 telescopes being built at IUCAA. Samir Dhurde and Tushar Purohit (outreach intern) from IUCAA were the resource persons during these.

International Year of Light (IYL2015): The theme of the utility of light and related technology, in Astronomy as well as various sciences, was highlighted via several lectures conducted on this topic.

IUCAA was a partner in an 11-day, amateur reflecting telescope making workshop, Organised by Vigyan Prasar, Government of India, in association with Pushpa Gunjal Science City, Kapurthala, Punjab, during October 2-16, 2015. [For details see Khagol, No.105, January 2016]

LIGO-INDIA OUTREACH

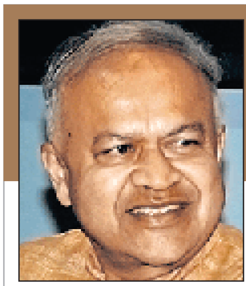
A special display model of the LIGO-India project was made with the help of Jyotirvidya Parisanstha. The model features real lasers and interference patterns.

NATIONAL SCIENCE DAY

The public watching the Focault Pendulum at IUCAA

Jayant Narlikar and Mangala Narlikar interacted with students and parents from the Malin village of the Ambegaon Taluka. The audience were the survivors of a major tragedy that the village suffered a few years back.

SECOND SATURDAY LECTURES



Date : 11-07-2015
Title : Cosmic Illusions (in English)

Speaker :
JAYANT NARLIKAR
(IUCAA)

Date : 08-08-2015
Title : How to infer the 'Life Story' of a Galaxy? (in English)

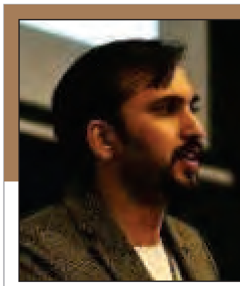
Speaker :
KAUSTUBH VAGHMARE
(IUCAA)

Date : 12-09-2015
Title : Wonderful Light – Curious Observations (in English)

Speaker :
G.V. PAVAN KUMAR
(IISER, PUNE)

Date : 10-10-2015
Title : Journey of a Photon – from Sun to Earth (in English)

Speaker :
DURGESH TRIPATHI
(IUCAA)

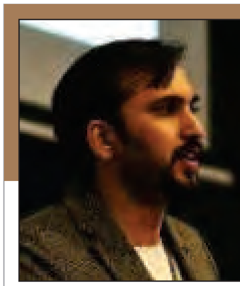


Date : 12-09-2015
Title : Wonderful Light – Curious Observations (in Marathi/Hindi)

Speaker :
SAMIR DHURDE
(IUCAA)

Date : 09-01-2016
Title : Studying Galaxies in Radio Light (in English)

Speaker :
YOGESH WADADEKAR
(NCRA)



Date : 12-12-2015
Title : Pluto Unleashed (in English)

Speaker :
SAMIR DHURDE
(IUCAA)

Date : 13-02-2016
Title : Gravitational Wave Astronomy: Opening New Windows to the Universe (in Marathi/Hindi)

Speaker :
BHOOSHAN GADRE
(IUCAA)

Date : 13-02-2016
Title : Gravitational Wave Astronomy: Opening New Windows to the Universe (in English)

Speaker :
SANJIT MITRA
(IUCAA)

IUCAA SPONSORED MEETINGS AND EVENTS AT VARIOUS UNIVERSITIES IN INDIA

WINTER SCHOOL ON GENERAL RELATIVITY AND ITS APPLICATIONS

The winter school, conducted at North Bengal University, Siliguri, during November 23 -28, 2015.
[For details see Khagol, No.105, January 2016]

WORKSHOP ON NOVAE AND ACCRETING BINARIES: A MULTI-WAVELENGTH STUDY

Workshop on Novae and Accreting Binaries: A Multi-Wavelength Study was conducted at the Centre for Excellence in Basic Science (CBS), University of Mumbai, during December 2 - 6, 2015 and Jointly organised by CBS and IUCAA, and generously funded by Infosys Foundation. [For details see Khagol, No.105, January 2016]

WORKSHOP ON ASRONOMY WITH SMALL TELESCOPE

School of Physical Science, S.R.T.M University, Nanded, Maharashtra, has conducted a workshop on Astronomy with Small Telescopes during December 8 - 11, 2015, and jointly organised by IUCAA and S.R.T.M. University.

[For details see Khagol, No.105, January 2016]

WORKSHOP ON GENERAL RELATIVITY AT ITS CENTENNIAL

To celebrate the centenary year of General Relativity, a scientific meeting was organised at the Centre for Theoretical Physics, Jamia Millia Islamia (CTP-JMI), New Delhi, during December 10 - 12, 2015. [For details see Khagol, No.105, January 2016]

NORTH EAST MEET OF ASTRONOMERS - 2015

North East Meet of Astronomers was organised at the Department of Physics, Tezpur University, during October 26-28, 2015

RESEARCH

Sk. Saiyad Ali

Tapering the sky response for angular power spectrum estimation from low-frequency radio-interferometric data

It is important to correctly subtract point sources from radio-interferometric data in order to measure the power spectrum of diffuse radiation like the galactic synchrotron or the Epoch of Reionization 21cm signal. It is computationally very expensive and challenging to image a very large area and accurately subtract all the point sources from the image. The problem is particularly severe at the sidelobes and the outer parts of the main lobe where the antenna response is highly frequency dependent and the calibration also differs from that of the phase centre. Here we show that it is possible to overcome this problem by tapering the sky response. Using simulated 150 MHz observations, we demonstrate that it is possible to suppress the contribution due to point sources from the outer parts by using the Tapered Gridded Estimator to measure the angular power spectrum C_ℓ of the sky signal. We also show from the simulation that this method can self-consistently compute the noise bias and accurately subtract it to provide an unbiased estimation of C_ℓ. This work has been done in collaboration with S. Choudhuri, S. Bharadwaj, N. Roy and A. Ghosh.

Fisher matrix predictions for detecting the cosmological 21 cm *signal with the Ooty Wide Field Array (OWFA)*

We have used the Fisher matrix formalism to quantify the prospects of detecting the $z = 3.35$ redshifted 21cm HI power spectrum with the upcoming radio-imterferometric array OWFA. OWFA's frequency and baseline coverage spans comoving Fourier modes in the range $1.8 \times 10^{-2} \leq k \leq 2.7\,\mathrm{Mpc}^{-1}$. The OWFA HI signal, however, is predominantly from the range $k \leq 0.2\,\mathrm{Mpc}^{-1}$. The larger modes, though abundant, do not contribute much to the HI signal. In this work, we have focused on combining the entire signal to achieve a detection. We find that a $5-\sigma$ detection of A_{HI} is possible with ~ 150 hr of observations, here A^2_{HI} is the amplitude of the HI power spectrum. We have also carried out a joint analysis for A_{HI} and β, the redshift space distortion parameter. Our study shows that OWFA is very sensitive to the amplitude of the HI power spectrum. However, the anisotropic distribution of the $\mathbf{k}$ modes does not make it very suitable for measuring β. This work has been done in collaboration with S. Bharadwaj and A. K. Sarkar.

G. Ambika

Complex networks of natural numbers and airports

Complex networks form the key tool for understanding the behaviour of complex systems from diverse fields like biology, ecology, technology and social sciences. Thus, a large variety of systems like transportation systems, power grids, web-pages, face book or internet, neurons, etc. built up of a collection of similar objects that are interacting with each other be studied using the framework of complex networks. Recently this has been extended to the study of novel patterns in natural numbers based on their divisibility. Such network is inherently different from other complex networks like social networks, in which it is deterministic with a unique identity for each node. This work has been done in collaboration with Snehal Shekatkar and Chandrasheel Bhagwat from IISER Pune.

A parallel study has led to a relatively simple model to study the connectivity patterns between airports in USA and Europe, where the domestic and international connections together make the system a network of networks. This is called RAIN (RAndom Interacting Network) model statistically relates intra-network features to inter-network structure and as such is very general and adaptable to various real-world complex systems. This project has been supported by the Department of Science and Technology, Government of India, and done in collaboration with Snehal Shekatkar and Juergen Kurths.

Effect of data gaps on correlation dimension computed from light curves of variable stars

Observational astrophysical data is often limited by gaps in data that arises due to lack of observations for a variety of reasons. Such gaps are usually smoothed over using interpolation techniques that can introduce artificial effects, especially when non-linear analysis is undertaken. A recent study reported shows how such gaps can affect the computed values of correlation dimension of the system, without using any interpolation. For this, gaps are introduced artificially in synthetic data derived from standard chaotic systems, like the Rssler and Lorenz, with frequency of occurrence and size of missing data drawn from two Gaussian distributions. Then the changes in correlation dimension with change in the distributions of position and size of gaps are studied. This study gives interesting results that for a considerable range of mean gap frequency and size, the value of correlation dimension is not significantly affected, indicating that in such specific cases, the calculated values can still be reliable and acceptable. Thus the study introduces a method of checking the reliability of computed correlation dimension values by calculating the distribution of gaps with respect to its size and position. This is illustrated for the data from light curves of three variable stars, R Scuti, U Monocerotis and SU Tauri. It is also shown how a cubic spline interpolation can cause a time series of Gaussian noise with missing data to be misinterpreted as being chaotic in origin. This is demonstrated for the non chaotic light curve of variable star SS Cygni, which gives a saturated D2 value, when interpolated using a cubic spline. However, a careful choice of binning, in addition to reducing noise, can help in shifting the gap distribution to the reliable ranges. The study was carried out in collaboration with Sandip V. George and Ranjeev Misra.

Ritabrata Biswas

Thermodynamic products in Horava-Lifshitz gravity with logarithmic correction of entropy

Properties of Cauchy horizon of a black hole is a matter of interest. In literature we can find several examples where different thermodynamic products (radius of event horizon, entropy, Hawking temperature, free energy, specific heat, etc.) are calculated. From the idea of CFT, some of these products are free of the BH mass, indicating the fact that they are universal thermodynamic properties. Beside the Schwarzschild or de Sitter BHs, the thermodynamic products for Horava-Lifshitz gravity is also studied. Our motivation is to note the change if we take account of the logarithmic correction of entropy formula. We calculate the thermodynamic product for Hawking temperature and specific heat for Kehaghius-Sfetsos BH and compared with the existing result (Pradhan in Phys. Lett. B **747, 64, 2015**. We comment on the stability of event and Cauchy horizons as well as from the physical interpretation, and C_+ vs M and C_- vs M curves are drawn. This work has been done in collaboration with Abhijit Mandal.

Three dimensional charged interior solutions admitting conformal Killing vectors

Investigation of new class of solutions for charged fluid distribution in (2+1) dimension admitting conformal motion of Killing vectors has always become a subject of special interest to the physicist in recent years. In this work, we present some new types of non-singular model for anisotropic charged fluid in (2+1) dimensions. The solutions obtained here satisfy all the regularity conditions at the origin. We have discussed various physical properties of the model. This work has been done in collaboration with Arkopriya Mallick, Indrani Karar and Farook Rahaman.

Subenoy Chakraborty

An analytic model for interacting dark energy and its observational constraints

This work deals with a theoretical model for interacting dark energy. The interaction between the cold dark matter (dust) and the dark energy has been assumed to be non-gravitational in nature. Exact analytic cosmological solutions are obtained, both for constant and variable equation of state for dark energy. It is found that for very small value of the coupling parameter (in the interaction term), the model asymptotically extends up to ΛCDM, while the model can enter into the phantom domain asymptotically, if the coupling parameter is not so small. Both the solutions are then analyzed with 194 Supernovae type Ia data. The best fit parameters are shown with 1σ and 2σ confidence intervals. We have also discussed the cosmographic parameters for both the cases. This work has been done in collaboration with S. Pan and S. Bhattacharya.

A model of the emergent Universe in inhomogeneous spacetime

The scenario of an emergent Universe is constructed in the background of an inhomogeneous spacetime model with an asymptotically (at spatial infinity) FRW spacetime. The cosmic substratum consists of two non-interacting components, namely (a) homogeneous and isotropic fluid that is dissipative in nature, and (b) an inhomogeneous and anisotropic barotropic fluid. In the non-equilibrium thermodynamic prescription(second order deviations), the particle creation mechanism is considered the cause for the dissipative phenomena. It is found that for a constant value of the particle creation rate parameter there exists a scenario of an emergent Universe. This work has been done in collaboration with S. Bhattacharya.

Ramesh Chandra

Peculiar stationary EUV wave in the eruption on 2011 May 11

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

Interrupted eruption of large quiescent filament associated with a halo CME

We analyze the observations of an eruptive quiescent filament associated with a halo Coronal Mass Ejection (CME). We use the observations from the Atmospheric Imaging Assembly (AIA) instrument onboard the Solar Dynamics Observatory (SDO), Solar and Heliospheric Observatory (SOHO)/Large Angle and Spectrometric Coronagraph (LASCO), and the Solar Terrestrial Relations Observatory (STEREO A/B) satellites. The filament exhibits a slow-rise phase followed by a gradual acceleration and then completely disappears. The filament could be traced in STEREO observations up to an altitude of about 1.44 R, where its rise speed reached 14 km/s and disappeared completely at about 10 : 32 UT on 2011 October 21. The CME associated with the filament eruption and two bright ribbons in the chromosphere both appeared at about 01 : 30 UT on October 22, i.e., 15 hr after the filament eruption was seen in He II 304 filtergrams. This delay is abnormally large even if the slow rise speed and slow acceleration of the filament are taken into account. To understand the cause of this delay, we compute the decay index (n) of the overlying coronal magnetic field. The height distribution of the decay index, n, suggests that the zone of instability ($n > 1$) at a lower altitude, 144,480 Mm, is followed by a zone of stability ($n < 1$) between 540 and 660 Mm. We interpret the observed delay to be due to the presence of the latter zone, i.e., the zone of stability, which could provide a second quasi-equilibrium state to the filament until it finally erupts. This work has been done in collaboration with S. Gosan, B. Filippov and R. A. Maurya.

Suresh Chandra

Collisional excitation of thioformaldehyde and of Silylidene

For analysis of spectrum of a molecule in the interstellar medium, radiative and collisional transition probabilities for rotational transitions in the molecule are required. We have calculated collisional rate coefficients for rotational transitions in ortho and para thioformaldehyde (H_2CS), and in ortho and para Silylidene (H_2CSi) due to collisions with He atom for kinetic temperatures 10, 20, 30, 40 and 50 K, following the procedure discussed in our earlier work. The accuracy of collisional rate coefficients may be within a factor of 2. This research has been done in collaboration with Mohit K. Sharma and Monika Sharma.

Search of amino group in the universe: 2-aminopyridine

In the search for life in the Universe, scientists are interested in identification of molecules, having amino (-NH_2) group, in the interstellar space. The aminoacetonitrile (NH_2CH_2CN), which is precursor of the simplest amino acid, the glycine (NH_2CH_2COOH), is identified near the galactic centre. The 2-aminopyridine ($H_2NC_5H_4N$) is of interest for the scientists, as it has close association with the life on the earth. Based on the spectroscopic studies, we have calculated the intensities of lines of 2-aminopyridine due to transitions between the rotational levels up to 47 cm^{-1} and have found a number of lines which may help in its identification in the interstellar medium. Frequencies of some of these transitions are found close to those detected in the envelope of IRC +10216 and not assigned to any of the known species. This work has been done in collaboration with Mohit K. Sharma, Monika Sharma and A. K. Sharma.

Surajit Chattopadhyay

Can holographic dark energy increase the mass of the wormhole?

This work is carried out in collaboration with Davood Momeni, Aziza Altaibayeva and Ratbay Myrzakulov of Eurasian National University, Kazakhstan. We have studied accretion of dark energy (DE) onto Morris Thorne wormhole with three different forms, namely: holographic dark energy, holographic Ricci dark energy and modified holographic Ricci dark energy. Considering the scale factor in power-law form, we have observed that as the holographic dark energy accretes onto wormhole, the mass of the wormhole is decreasing. In the next phase, we have considered three parameterization schemes that are able to get hold of quintessence as well as phantom phases. Without any choice of scale factor, we reconstructed Hubble parameter from conservation equation and dark energy densities and subsequently got the mass of the wormhole separately for accretion of the three dark energy candidates. It was observed that if these dark energies accrete onto the wormhole, then for quintessence stage, wormhole mass decreases up to a certain finite value and then again increases to aggressively during phantom phase of the universe.

Holographic polytropic $f(T)$-gravity models

This work has been carried out in collaboration with Abdul Jawad and Shamaila Rani of COMSATS Institute of Information Technology, Pakistan, which reports a study on the cosmological consequences arising from reconstructing $f(T)$ gravity through new holographic-polytropic dark energy. Viewing $f(T)$ as an effective description of the underlying theory of DE, and considering the new holographic polytropic dark energy as pointing in the direction of the underlying theory of DE, we have studied how the modified-gravity can describe the new holographic polytropic dark energy as effective theory of DE. We have carried out this work through two approaches. In the first approach we have chosen $H = H_0 + \frac{H_1}{t}$ and consequently reconstructed $f(T)$, that is found to tend to 0 with T tending to 0 and thereby satisfying one of the sufficient conditions for a realistic model. The effective torsion EoS parameter coming out of this reconstructed $f(T)$ is found to stay above -1 in contradiction to w_{tot} showing a clear transition from quintessence to phantom, i.e., quintom. The deceleration parameter exhibits transition from decelerated to accelerated phase. The statefinder parameters $\{r, s\}$ could attain ΛCDM $\{r = 1, s = 0\}$ and could go beyond it. More particularly, it has been apparent from the statefinder plot that for finite r we have $s \to -\infty$ that indicates dust phase. Hence this reconstructed $f(T)$ model interpolates between dust and ΛCDM phase of the universe.

In the second approach instead of considering any particular form of the scale factor we have assumed a power-law and exponential solutions for $f(T)$. Under power-law solution we derived expressions for $\dot{H}$ in terms of a. Thereafter we derived effective torsion EoS and deceleration parameters and also the statefinder parameters. For this reconstructed H, the $f(T)$ has been found to behave like the earlier approach that is tending to 0 as T tends to 0. As plotted against redshift z, the effective torsion EoS as well as w_{tot} are found to exhibit phantom-like behaviour. The deceleration parameter is found to stay negative, i.e., exhibited accelerated expansion. Although the statefinder plot could attain ΛCDM, no clear attainment of dust phase is apparent. Under exponential solution of $f(T)$ we derived expressions for $\dot{H}$ in terms of a and subsequently reconstructed f does not tend to 0 as T tends to 0 and hence, it does not satisfy the sufficient condition for realistic model. The effective torsion EoS parameter derived this way exhibited phantom-like behaviour. However, w_{total} exhibits a transition from > -1 to < -1 for $n = 6$.

Tanuka Chattopadhyay

Multivariate analysis of the globular clusters in M87

Tanuka Chattopadhyay with Sukanta Das and Emmanuel Davoust has carried out an objective classification of 147 globular clusters (GCs) in the inner region of the giant elliptical galaxy M87 with the help of two methods of multivariate analysis. First, independent component analysis (ICA) is used to determine a set of independent variables that are linear combinations of various observed parameters (mostly Lick indices) of the GCs. Next, K-means cluster analysis (CA) is applied on the independent components (ICs), to find the optimum number of homogeneous groups having an underlying structure. The properties of the four groups of GCs thus uncovered are used to explain the formation mechanism of the host galaxy. It is suggested that M87 formed in two successive phases. First a monolithic collapse, which gave rise to an inner group of metal-rich clusters with little systematic rotation and an outer group of metal-poor clusters in eccentric orbits. In a second phase, the galaxy accreted low-mass satellites in a dissipationless fashion, from the gas of which the two other groups of GCs formed. Evidence is given for a blue stellar population in the more metal rich clusters, which we interpret by Helium enrichment. Finally, it is found that the clusters of M87 differ in some of their chemical properties (NaD, TiO1, light-element abundances) from GCs in our galaxy and M31.

Bhag Chand Chauhan

Light sterile neutrinos and dark sector of universe

It is amazing to learn that about 95% of the universe is dark. The search for this dark side of universe is continuously going on for decades. In this work, the current understanding of dark matter and its various possible constituents are presented. Neutrino being a weakly interacting, neutral, and light particle can play a crucial role in the dynamics of early universe and formation of dark matter. On the other hand, the neutrino oscillation data reported various anomalies; these anomalies are, e.g., in LSND and MiniBooNE results, a re-analysis of the anti-neutrino flux produced by nuclear power reactors, calibration runs using ^{51}Cr and ^{37}Ar radioactive sources in the GALLEX and SAGE, upturn expected from LMA MSW and time modulation in low energy solar neutrino signal, which indicate new physics, including the possibility of additional low-mass sterile neutrino states. A number of theoretical proposals, phenomenological exercises and new experimental efforts are coming up that could eventually solve these puzzles. Revisiting our model proposed a couple of years ago would be of great interest. The model is based on the interaction of neutrino magnetic moment with large solar magnetic fields leading to conversion of active into sterile neutrinos. It may be noted that the model solves most of these puzzles in the solar neutrino flux, including time modulation. The author has reviewed the predictions of the model in the light of recent developments in the field. Possible implication of the light sterile neutrinos in the dark sector of universe is also included in discussion.

Geothermal energy and earthquakes in Western Himalayas

It is well corroborated that the earth is relentlessly bubbling inside, since its birth and traversing continuously through a geological change. The source of this dynamism is the heat stored inside, i.e., the geothermal energy, which is believed to be the product of mainly the decay of natural radioisotopes in the crust and mantle, and in the core of earth. This heat exerts pressure towards the surface, where it leads to earthquakes and geothermal events like spectacular volcanoes and fumaroles. The Himalayan mountains are the youngest ranges amongst various developments in the crust of earth. As per the scientists and observed facts, this region is the highest seismic prone zone. In our previous work we have shown, on the basis of substantial observed fact, that the intensity of earthquake can be abated by utilizing the geothermal power. In this work, we focus on the state of Himachal Pradesh, which falls in the base of the Western Himalayas . Given the region of zone-V, the earthquake disaster management is one of the major challenges in the state. It is argued that by harnessing geothermal power from various sites in the stats, the intensity and risk due to earthquake disaster can be made less detrimental.

Himadri Sekhar Das

Extinction map of a small globule

In collaboration with A. Barman, the author has constructed extinction map of a small globule CB 224. The column density distribution of molecular cloud can be studied through thermal continuum imaging of the cold dust, CO mapping or extinction maps. The Near Infrared Color Excess (NICE) method is an excellent tool to determine the visual extiction from measurement of NIR colour excess and also to map the dust column density through star forming clouds. In this work, the visual extinction map of a small and roundish globule CB 224 has been constructed using the NICE method. The map shows one core near to the centre of the globule, which is highly extincted and shows the maximum optical extinction of 17.2 magnitude. The central column density is estimated to be $N_H = 3.4 \times 10^{22} cm^{-2}$ mag^{-1}. The visual extinction map, is also compared with the SCUBA 850 μm continuum map, which also shows one prominent core close to the centre of the globule. This study shows that the visual extinction map matches well with 850μm continuum map, which is quite expected as the region of higher visual extinction corresponds to higher densities of dust.

Distance estimation of some selected small Bok globules

The author in collaboration with A. Das and A. S. Devi has determined the distances to six small Bok globules (CB 17, CB 24, CB 188, CB 224, CB 230 and CB 240) using near-infrared photometry (2MASS JHK$_S$ colours). The distances to these clouds are estimated to be 478 ± 88, 293 ± 54, 262 ± 49, 378 ± 70, 293 ± 54 and 429 ± 79 pc, respectively.

Sudipta Das

Study of non-canonical scalar field model using various parametrizations of dark energy equation of state

In this work, we try to build up a cosmological model using a non-canonical scalar field within the framework of a spatially flat FRW spacetime. In this context, we have considered four different parametrizations of the equation of state parameter. Analytical solutions for various cosmological parameters have been found out. It has been found that the deceleration parameter shows a smooth transition from a positive value to some negative value, which indicates that the universe was undergoing an early deceleration followed by late time acceleration which is essential for the structure formation of the universe. It has been found that one of the models (Generalized Chaplygin gas model) mimics the concordance $\wedge$ CDM in the near future, whereas two other models (CPL and JBP) diverge due to future singularity. Finally, we have studied these theoretical models with the latest datasets from SN Ia+ H(z) +BAO/CMB. This work has been done in collaboration with Abdulla Al Mamon.

A divergence free parametrization of deceleration parameter for scalar field dark energy

In this research, we have considered a spatially flat FRW universe filled with pressureless matter and dark energy (DE) with a phenomenological parametrization of the deceleration parameter q(z) and then we have reconstructed the equation of state (EoS) for DE $\omega\phi(z)$. This divergence free parametrization of the deceleration parameter is inspired from one of the most popular parametrization of the DE EoS given by Barboza and Alcaniz [see E. M. Barboza and J. S. Alcaniz, Phys. Lett. B, **666** (2008) 415]. Using the combination of datasets (SN Ia + Hubble + BAO/CMB), we have constrained the transition redshift z_t (at which the universe switches from a decelerating to an accelerating phase) and have found the best fit value of z_t. We have also compared the reconstructed results of $q(z)$ and $\omega_\phi(z)$ and have found that the results are compatible with a Λ CDM universe if we consider SN Ia + Hubble data but inclusion of BAO/CMB data makes $q(z)$ and $\omega_\phi(z)$ incompatible with Λ CDM model. The potential term for the present toy model is found to be functionally similar to a Higgs potential. This work has been done in collaboration with Abdulla al Mamon.

Ujjal Debnath

Accretion of dark energy onto higher dimensional charged BTZ black hole

We have studied the accretion of charged BTZ like black hole (BH) in $(n+2)$ dimensions. The mass of the BTZ BH has been calculated and we have observed that the mass of the BTZ BH is related to square root of the energy density of dark energy which accretes onto BH in our accelerating FRW universe. We have assumed modified Chaplygin gas (MCG) as a candidate of dark energy which accretes onto BH and we have found the expression of BTZ BH mass. Since in our solution of MCG, this model generates only quintessence dark energy (not phantom) and so BTZ BH mass increases during the whole evolution of the accelerating universe. Next we have assumed 5 kinds of parametrizations of well known dark energy models. These models generate both quintessence and phantom scenarios, i.e., phantom crossing models. So if these dark energies accrete onto the BTZ BH, then in quintessence stage, BH mass increases upto a certain finite value and then decreases for phantom stage during whole evolution of the universe.

Generalized second law of thermodynamics for non-canonical scalar field model with corrected-entropy

We have considered a non-canonical scalar field dark energy model in the framework of flat FRW background. It has been assumed that the dark matter sector interacts with the non-canonical dark energy sector through some interaction term. Using the solutions for this interacting non-canonical scalar field dark energy model, we have investigated the validity of generalized second law (GSL) of thermodynamics in various scenarios using first law and area law of thermodynamics. For this purpose, we have assumed two types of horizons, viz, apparent horizon and event horizon for the universe and using the first law of thermodynamics, we have examined the validity of GSL on both horizons. Next, we have considered two types of entropy-corrections on these horizons. Using the modified area law, we have examined the validity of GSL of thermodynamics on these horizons under some restrictions of model parameters. This work has been done in collaboration with Sudipta Das and Abdulla Al Mamon.

S. Dev

Neutrino mass matrices with two vanishing elements/cofactors

We study the phenomenological implications of the recent neutrino data for class B of two texture zeros and two vanishing cofactors for Majorana neutrinos in the flavour basis. We find that the classes B_1 (B_2) of two texture zeros and the classes B_5 (B_6) of two vanishing cofactors have similar predictions for neutrino oscillation parameters for the same mass hierarchy. Similar predictions for the classes B_3 (B_4) of two texture zeros and classes B_3 (B_4) of two vanishing cofactors are expected. However, a preference for a shift in the quadrant of the Dirac-type CP-violating phase (δ) in contrast to the earlier analysis has been predicted for a relatively large value of the reactor neutrino mixing angle (θ_{13}) for class B of two texture zeros and two vanishing cofactors for an inverted mass spectrum. No such shift in the quadrant of δ has been found for the normal mass spectrum. This work has been done in collaboration with Lal singh and Desh Raj.

Broja Gopal Dutta

Lag variability of GRS 1915+105 during plateau states

Galactic microquasar GRS 1915+105 exhibits fast variability during class transitions and at least seventeen types of variability classes are observed. The energy dependent time-lag and QPO frequency variation is reported for black hole candidates.We present a study of timel-lags and Quasi Periodic Oscillations (QPOs) for these classes. We calculate time-lag behaviour of GRS 1915+105 during its plateau states. The evolution of time-lags are correlated with the accretion geometry during plateau states of GRS 1915+105. We find that the lag spectrum for the χ_3 class is different from that of χ_1, χ_2 and χ_4 classes. Hard lags occur only when Comptonizing efficiency (CE) $\geq 0.9\%$ for different plateau states and its evolution confirm the sequence of class transitions suggested on the basis of CE parameter. We concluded that the variation of time-lags could be due to the movement of CENBOL. This complex pattern of the time-lag has resemblance to that observed in high inclination sources (XTE J1550-564, GRO J1655-40 and XTE 1859 +226) but for low inclination sources (GX 339-4, for 2002, 2004, 2007 and 2010 outbursts and XTE 1650-500, for 2001 outbursts) we always find hard lags, which suggest the oscillations of CENBOL during different class transitions. This work has been done in collaboration wtih P. S. Pal and S. K. Chakrabarti.

Inclination effects and time variability properties of black hole transients

We study time variability properties of black hole transients densely monitored by the RXTE instruments. We find hard lag, intregated over Quasi Periodic Oscillation (QPO) frequency for the low inclination source (such as GX 339-4). The hard lag monotonically decreases and become negative (i.e., soft lag happens) close to 3.0 Hz for the high inclination sources (e.g., XTE J1550-564). Thus, we find two different behaviours for the high inclination and the low inclination systems. We also find that the evolution properties of low-frequency QPOs do not depend on the orbital inclination, though the amplitude of it depends on the orbital inclination, We conclude these evolutions could be due to the systematic movement of the Comptonizing region itself confirming the propagatory shock oscillation model, and the time lag is not only a function of the average energy of the emitted photons; it is also a function of the inclination angle of the binary system. What is clear in both high and low inclination systems is that the lag increases when QPO frequency goes down, i.e., the Comptonizing region whose oscillation causes QPOs goes up. What is not obvious so far is the reason why the lag changes sign at a specific QPO frequency, i.e., at a specific size of the Compton cloud. This has been resolved recently in Dutta and Chakrabarti (2016, accepted in ApJ). We find that the major processes are (i) repeated Compton scattering, (ii) reflection of hard X-rays from the Keplerian disk and (iii) focusing due to gravitational bending. We showed that if we add up the qualitative variations of lag, then the high inclination objects could have negative time lag, i.e., soft photons appearing before hard photons due to reflection and focussing effects. We see this effect in XTE J1550-564 at frequencies higher than ~ 3.2Hz. This work has been done in collaboration with S.K. Chakrabarti

Jibitesh Dutta

Cosmological dynamics of scalar fields with kinetic corrections: Beyond the exponential potential

We expand the dynamical systems investigation of cosmological scalar fields characterized by kinetic corrections presented in N. Tamanini, Dynamics of cosmological scalar fields [Phys. Rev. D, **89**, 083521 (2014)]. In particular, we do not restrict the analysis to exponential potentials only, but we consider arbitrary scalar field potentials and derive general results regarding the corresponding cosmological dynamics. Two specific potentials are then used as examples to show how these models can be employed not only to describe dark energy, but also to achieve dynamical crossing of the phantom barrier at late times. Stability and viability issues at the classical level are also discussed. This work has been done in collaboration with Wompherdeiki Khyllep and Nicola Tamanini

Late-time accelerated scaling attractors in DGP (Dvali-Gabadadze-Porrati) braneworld

In the evolution of late universe, the main sources are dark energy and dark matter. They are indirectly detected only through their gravitational manifestations. So the possibility of interaction with each other without violating observational restrictions is not ruled out. With this motivation, we investigate the dynamics of DGP brane world, where source of dark energy is a scalar field and it interacts with matter source. Since observation favours phantom case more, we have also studied the dynamics of interacting phantom scalar field. In non-interacting DGP brane world, there are no late-time accelerated scaling attractors, and hence cannot alleviate the coincidence problem. In this work, we show that it is possible to get late-time accelerated scaling solutions. The phase space is studied by taking two categories of potentials (exponential and non-exponential functions). The stability of critical points are examined by taking two specific interactions. The first interaction gives late-time accelerated scaling solution for phantom field only under exponential potential, while for second interaction we do not get any scaling solution. Furthermore, we have shown that this scaling solution is also classically stable. This work has been done in collaboration with Wompherdeiki Khyllep and Erickson Syiemlieh.

Sukanta Dutta

Anomalous X-ray galactic signal from 7.1 keV spin-3/2 dark matter decay

In order to explain the recently reported peak at 3.55 keV in the galactic X-ray spectrum, we propose a simple model. The Standard Model is extended by including a neutral spin-3/2 vector-like Fermion that transforms like a singlet under SM gauge group. This 7.1 keV spin-3/2 Fermion is considered to comprise a portion of the observed dark matter. Its decay into a neutrino and a photon commensurate with the observed data, fits the relic dark matter density and obeys the astrophysical constraints from the supernova cooling. This work has been done in collaboration with A. Gopal and S. Kumar.

Measuring anomalous Wtb couplings at e^-p collider

We study the accuracy with which the lowest order CP conserving anomalous Wtb couplings in the single top quark production at the proposed large hadron electron collider (LHeC) can be probed.

The one dimensional distribution of various kinematic observables at the parton level MC and their asymmetries arising due to the presence of anomalous couplings both in the hadronic and leptonic W decay is examined. We find that at 95 % C.L., the anomalous coupling associated with the left handed vector current can be measured at an accuracy of the order of $\sim 10^{-2} - 10^{-3}$, while those associated with the right handed vector and left as well as right handed tensor currents have sensitivity at the order of $\sim 10^{-1} - 10^{-2}$ for the systematic uncertainty varying between 10% - 1% at an integrated luminosity of 100 fb^{-1}. A comprehensive analysis of the combined covariance matrix derived from all one dimensional distributions of kinematical observables is used to compute the errors in anomalous couplings. This work has been done in collaboration with A. Goyal, M. Kumar and B. Mellado.

Sunandan Gangopadhyay

Path integral action and exact renormalization group dualities for quantum systems in non-commutative plane

We employ the path integral approach developed in S. Gangopadhyay and F. E. Scholtz, [Phys. Rev. Lett., **102** (2009) 241602] to discuss the (generalized) harmonic oscillator in a non-commutative plane. The action for this system is derived in the coherent state basis with additional degrees of freedom. From this, the action in the coherent state basis without any additional degrees of freedom is obtained. This gives the ground-state spectrum of the system. We then employ the exact renormalization group approach to show that an equivalence can be constructed between this (non-commutative) system and a commutative system.

Constraints on the generalized uncertainty principle from black hole thermodynamics

In this work, we calculate the modification to the thermodynamics of a Schwarzschild black hole in higher dimensions due to the generalized uncertainty principle (GUP). We use the fact that the leading-order corrections to the entropy of a black hole has to be logarithmic in nature to restrict the form of the GUP. We observe that in six dimensions, the usual GUP produces the correct form for the leading-order corrections to the entropy of a black hole. However, in five and seven dimensions a linear GUP, which is obtained by a combination of DSR with the usual GUP, is needed to produce the correct form of the entropy of a black hole. Finally, we demonstrate that in five dimensions, a new form of GUP containing quadratic and cubic powers of the momentum also produces the correct form for the leading-order corrections to the entropy of a black hole. This work has been done in collaboration with Abhijit Dutta and Mir Faizal.

Sushant Ghosh

A non-singular rotating black hole:

The spacetime singularities in classical general relativity are inevitable, as predicated by the celebrated singularity theorems. However, it is a general belief that singularities do not exist in Nature and they are the limitations of the general relativity. In the absence of a well defined quantum gravity, models of regular black holes have been studied. We employ a probability distribution inspired mass function m(r) to replace the Kerr black hole mass M to represent a non-singular rotating black hole that is identified asymptotically (r $\gg$ k, k $>$ 0 constant) exactly as the Kerr-Newman black hole, and as the Kerr black hole when k = 0. The radiating counterpart renders a non-singular generalization of Carmeli's spacetime as well as Vaidyas spacetime, in the appropriate limits. The exponential correction factor changing the geometry of the classical black hole to remove the curvature singularity can also be motivated by quantum arguments. The regular rotating spacetime can also be understood as a black hole of general relativity coupled to nonlinear electrodynamics.

Horizon structure of rotating Bardeen black hole and particle acceleration:

We investigate the horizon structure and ergosphere in a rotating Bardeen regular black hole, which has an additional parameter (g) due to magnetic charge, apart from mass (M) and rotation parameter (a). Interestingly, for each value of parameter g, there exist a critical rotation parameter ($a = a_E$), which corresponds to an extremal black hole with degenerate horizons, while for $a < a_E$ describes a non-extremal black hole with two horizons, and no black hole for $a > a_E$. We find that the extremal value aE is also influenced by the parameter g and so is the ergosphere. While the value of aE remarkably decreases when compared with the Kerr black hole, the ergosphere becomes more thicker with increase in g. We also study collision of two equal mass particles near the horizon of this black hole, and explicitly bring out the effect of parameters g. The centre-of-mass energy (ECM) not only depends on rotation parameter a, but also on parameter g. It is demonstrated that the ECM could be arbitrary high in the extremal cases when one of the colliding particle has critical angular momentum, thereby suggesting that the rotating Bardeen regular black hole can act as a particle accelerator. This work has been done in collaboration with Muhammed Amir.

Rupjyoti Gogoi

Comparison of diffuse infrared and far-ultraviolet emission in the Large Magellanic Cloud

Dust scattering is the main source of diffuse emission in the far-ultraviolet (FUV). For several locations in the Large Magellanic Cloud (LMC), Far Ultraviolet Spectroscopic Explorer (FUSE) satellite has observed diffuse radiation in the FUV with intensities ranging from 1,000 - 3×10^5 photon units and diffuse fraction between $5\% - 20\%$ at 1,100 $\AA$. We compare the FUV diffuse emission with the mid-infrared (MIR) and far-IR (FIR) diffuse emission observed by the Spitzer space telescope and the Akari satellite for the same locations. The intensity ratios in the different MIR and FIR bands for each of the locations will enable us to determine the type of dust contributing to the diffuse emission as well as to derive a more accurate 3D distribution of stars and dust in the region, which in turn may be used to model the observed scattering in the FUV. We have studied the infrared (IR) data for two different regions in LMC, namely N11 and 30 Doradus, and observed a better FUV $\sim$ IR correlations for N11 as compared to 30 Doradus. This work has been done in collaboration with Gautam Saikia, P. Shalima and Amit Pathak.

Sarbari Guha

Particle motion and perturbed dynamical system in warped product spacetimes

In this work we have used the dynamical systems analysis to study the dynamics of a five dimensional universe in the form of a warped product spacetime with a spacelike dynamic extra dimension. We have decomposed the geodesic equations to get the motion along the extra dimension and have studied the associated dynamical system when the cross-diagonal element of the Einstein tensor vanishes, and also when it is non-vanishing. Introducing the concept of an energy function along the phase path in terms of the extra-dimensional coordinate, we have examined how the energy function depends on the warp factor. The energy function serves as a measure of the amount of perturbation of geodesic paths along the extra dimension in the region close to the brane. Then we studied the geodesic motion under a conventional metric perturbation in the form of homothetic motion, and conformal motion and examined the nature of critical points for a Mashhoon-Wesson type metric, for timelike and null geodesics when the cross-diagonal term of the Einstein tensor vanishes. Finally, we investigated the motion for null and timelike geodesics under the condition when the cross diagonal element of the Einstein tensor is non-vanishing and examined the effects of perturbation on the critical points of the dynamical system. This work has been done in collaboration with Pinaki Bhattacharya.

K. P. Harikrishnan

Uniform framwork for the recurence-network analysis of chaotic time series

The author, along with Rinku Jacob, Ranjeev Misra and G. Ambika, has proposed a general method for the construction and analysis of recurrence- networks from chaotic time series. The authors have shown that the critical threshold for the construction of recurrence-networks is closely linked to the embedding dimension. A small critical range has been identified that is approximately same for several standard chaotic time series for a fixed embedding dimension. This provides a uniform framework for the non-subjective comparison of the statistical measures of the recurrence-networks constructed from various chaotic attractors. The merits, limitations and potential applications of the proposed method are also highlighted.

Priya Hasan

The Thirty Metre Telescope

The Thirty Metre Telescope is a technologically ambitious project, with India participating with a 10% contribution. This work describes the project and a few of the science cases possible with the telescope.

Search for low-mass objects in the globular cluster M4. I. detection of variable stars

With every new discovery of an extrasolar planet, the absence of planets in globular clusters (GCs) becomes more and more conspicuous. Null detection of transiting hot Jupiters in GCs 47 Tuc, ω Cen, and NGC 6397 presents an important puzzle, raising questions about the role played by cluster metallicity and environment on formation and survival of planetary systems in densely populated stellar clusters. GCs were postulated to have many free-floating planets, for which microlensing (ML) is an established tool for detection. Dense environments, well-constrained distances and kinematics of lenses and sources, and photometry of thousands of stars simultaneously make GCs the ideal targets to search for ML. We present first results of a multisite, 69-night-long campaign to search for ML signatures of low-mass objects in the GC M4, which was chosen because of its proximity, location, and the actual existence of a planet. M4 was observed in R and I bands by two telescopes, 1m T40 and 18-inch C18, of the Wise Observatory, Tel Aviv, Israel, from 2011 April to July. Observations on the 1m telescope were carried out in service mode, gathering 12 to 48 20s exposures per night for a total of 69 nights. C18 observations were done for about 4 hr a night for six nights in 2011 May. We employ a semi-automated pipeline to calibrate and reduce the images to the light curves that our group is developing for this purpose, which includes the differential photometry package DIAPL, written by Wozniak and modified by W. Pych. Several different diagnostics are employed for search of variability/transients. While no high-significance ML event was found in this observational run, we have detected more than 20 new variables and variable candidates in the M4 field. This work has been done in collaboration with M. Safonova, D. Mkrtichian, F. Sutaria, N. Brosch, E. Gorbiko and P. Joseph.

K. Indulekha

Implications of some scenarios for the formation of bound stellar clwsters

The stellar initial mass function (IMF) is a direct input into many of our studies of the universe that is made visible to us by galaxies. Universality is expected for the IMF from the scale free nature of the processes considered to control star formation, turbulence and gravity. Considering the relation between the total stellar mass in a cluster and the highest mass star it can harbour, Indulekha Kavila along with Babitha George and Anu Babu has explored the implications of some scenarios for the formation of bound stellar clusters, viz., variations in the mass spectrum of the cores/a density dependent SFE, on the integrated IMF. The cluster is taken as a congregation of sub-clusters. It is found that a flattening in the slope of the core mass function (CMF) of $\sim$1.5 produces a change of ~ 1.1 in the slope of the integrated IMF, and a change in the SFE from $0.1 - 0.8$ made the integrated IMF flatter by ~ 0.5. Also given the $m_{max} - M_{ecl}$ relation, a larger SFE always implies a larger turn down mass for the integrated IMF.

Naseer Bhat Iqbal

Entropy change and phase transitions in an expanding universe

This work complies a correlated study of a gravitational quasi-equilibrium thermodynamic approach for establishing and signifying a unique behaviour of the cosmological entropy and phase transitions in an expanding universe. On the basis of prescribed boundary conditions, the cluster temperature relation for the intra-cluster medium (ICM) of galaxy clusters has been derived. A more productive and signifying approach of the correlation function used for galaxy clustering phenomena shows a unique behaviour of entropy change, where a phenomena known as the gravitational phase transition occurs. The unique behaviour occurs with a symmetry breaking from mild clustering to low clustering and from mild clustering, to higher order clustering which differs from normal symmetry breaking in material sciences. We also derive results for the specific latent heat associated with the phase transitions of 3.20 T_c and 0.55 T_c for mildly clustered phase to the low clustered phase and from the mildly clustered phase to the highly clustered phase respectively. This work has been done in collaboration with T. Masood and N. Demir

A model for the energy-dependent time- lag and rms of the heart beat oscillations in GRS1915+105

Energy dependent phase lags reveal crucial information about the casual relation between various spectral components and about the nature of the accretion geometry around the compact objects.

The time lag and the fractional root mean square (rms) spectra of GRS 1915+105 in its heartbeat oscillation class / ρ state show peculiar behaviour at the fundamental and harmonic frequencies where the lags at the fundamental show a turnaround at $\sim$ 10 KeV, while the lags at the harmonic do not show any turn around at least till $\sim$ 20 KeV. The magnitude of lags is of the order of few seconds and hence cannot be attributed to the light travel time effects or comptonization delays. The continuum X ray spectra can roughly be described by a disk blackbody and a hard X ray power law component and from phase-resolved spectroscopy, it has been shown that the inner disc radius varies during the oscillation. Here,we propose that there is a delayed response of the inner radius to the accretion rate such that $r_{in}(t) \propto M^{\beta}(t - \tau_d)$ The fluctuating accretion rate drives the oscillations of the inner radius after a time delay τ_d while the power law component responds immediately. We show that in such a scenario a pure sinusoidal oscillation of the accretion rate can explain not only the shape and magnitude of energy dependent rms and timelag spectra at the fundamental but also the next harmonic with just four free parameters. This work has been done in collaboration with Mubashir Hamid Mir, Ranjeev Misra, Mayukh Pahari and Naveel Ahmad.

Deepak Jain

Transition redshift: New constraints from parametric and non-parametric

We use the Cosmokinematics approach to study the accelerated expansion of the Universe. This is a model independent approach and depends only on the assumption that the Universe is homogeneous and isotropic, and is described by the FRW metric. We parametrize the deceleration parameter, q(z), to constrain the transition redshift (z_t) at which the expansion of the Universe goes from a decelerating to an accelerating phase. We use three different parametrizations of q(z) namely, $q_I(z) = q_1 + q_2 z$, $q_{II}(z) = q_3 + q_4 ln(1 + z)$ and $q_{III}(z) = \frac{1}{2} + q_5/(1+z)^2$. A joint analysis of the age of galaxies, strong lensing and supernovae Ia data indicates that the transition redshift is less than unity, i.e. $z_t < 1$, We also use a non-parametric approach (LOESS+SIMEX) to constrain z_t. This too gives $z_t < 1$, which is consistent with the value obtained by the parametric approach. This work has been done in collaboration with N. Rani, S. Mahajan, A. Mukherjee and N. Pires.

Mehedi Kalam

Theoretical investigation of the neutron star in low-mass X-ray binary X1822-371(V691 CrA)

Low-mass X-ray binaries (LMXBs) consist of a neutron star or black hole accreting material from a star similar to our Sun. The material is pulled into an accretion disk around the compact object and heated to millions of Kelvin. This causes it to emit at X-ray wavelengths. In the Milky Way, few hundred of LMXBs have been detected and only very a few of them have been detected in globular clusters. Chandra X-ray Observatory data has revealed LMXBs in a few more distant galaxies. LMXB emits radiation mostly in X-rays, which is less than one percent in the visible region. The orbital periods of LMXBs are ranges from ten minutes to several hundred days. LMXB X1822-371 (V691 CrA) is one of the brightest in the optical, and also it can be treated as the prototypical accretion disk corona (ADC) source. We propose a model for the neutron star in LMXB X1822-371 (V691 CrA). Here we investigate the physical phenomena of the neutron star by using the Tolman-IV solution. Using our model, we have calculated central density, surface density, central pressure, surface red-shift and probable radius of the above mentioned neutron star, which is very much consistent with reported data. We also obtain a possible equation of state of the star which is physically acceptable. This work has been done in collaboration with SK. Monowar Hossein, Nur Farhad and Sajaham Molla.

Galactic rotation curves and strange quark matter with observational constraints

The galaxy rotation problem is the discrepancy between observed galaxy rotation curves and the Newtonian-Keplerian prediction, assuming a centrally-dominated mass associated with the observed luminous material. When masses of galaxies are calculated solely from the luminosities and mass-to-light ratios in the disk, and if core portions of spiral galaxies are assumed to approximate to those of stars, the masses derived from the kinematics of the observed rotation and the law of gravity do not match. This discrepancy can be accounted for by a large amount of dark matter that permeates the galaxy and extends into the galaxy's halo.

We, here, obtain the spacetime of the galactic core in the framework of general relativity by taking the flat rotational curve as input and considering the matter content in the galactic core region as strange quark matter. We also obtain the energy density, radial and tangential pressures of the core strange quark matter. Significantly, we have shown that Bag constant takes an important role to stabilize the circular orbit of the test particles. We also give a limit of the Bag constant for the existence of quark matter in the galactic halo region. This work has been done in collaboration with Farook Rahaman, SK. Monowar Hossein and Jayanta Naskar.

Nagendra Kumar

MHD waves in a stratified viscous Solar atmosphere

The magnetically structured solar atmosphere supports a variety of wave modes. Acoustic waves generated by the convective motions in the solar convection zone undergo the mode conversion, which takes place in the region where the sound and Alfven speeds are of comparable magnitude, i.e., the region where the plasma β, the ratio of gas pressure to magnetic pressure, is unity. The author and collaborators (Anil Kumar and K. Murawski) have studied MHD wave propagation in a gravitationally stratified isothermal viscous atmosphere of the Sun, permeated by uniform magnetic field. They have considered a one dimensional model composed of a gravitationally stratified viscous solar atmosphere with a uniform vertical magnetic field along the z-axis. MacCormack method is used to solve the MHD equations. This scheme is second order accurate in time and space. They have run the simulation for $-10 \leq z \leq 5$ with 5,001 grid points by choosing $\beta = 0.2$ and characteristic length equals to coronal scale height so that in simulation =1 corresponds to one coronal scale height.

It is found that when the wave passes from low-β to high-β plasma through the layer $\beta \approx$1 the mode conversion occurs at the point z≈-1.8 in this layer. Interference due the interaction of converted part (slow waves) and transmitted part (fast wave) of waves is observed but the size of interference region reduces to a slightly smaller than that obtained in the absence of viscosity. Fast wave fades out slightly earlier in the presence of viscosity. The amplitude of vertical velocity decreases gradually with z. The amplitude of horizontal velocity is smaller but the trend of variation of amplitudes with z. is similar to that obtained in the absence of viscosity. Thus, viscosity influences the amplitudes of horizontal and vertical velocities, the length of interference region, and the propagation of fast and slow waves. This work has been done in collaboration A. Kumar and K. Murawski.

Suresh Kumar

Consistency of the nonflat ΛCDM model with the new result from BOSS

Using 137,562 quasars in the redshift range $2.1 \leq z \leq 3.5$ from the data release 11 (DR11) of the baryon oscillation spectroscopic survey (BOSS) of Sloan Digital Sky Survey (SDSS)-III, the BOSS-SDSS collaboration estimated the expansion rate $H(z = 2.34) = 222 \pm 7$km/s/Mpc of the Universe, and reported that this value is in tension with the predictions of flat ΛCDM model at around a 2.5σ level. In this work, we briefly describe some attempts made in the literature to relieve the tension, and show that the tension can naturally be alleviated in a non-flat ΛCDM model with positive curvature. We also perform the observational consistency check by considering the constraints on the non-flat ΛCDM model from Planck, WP and BAO data. We find that the non-flat ΛCDM model constrained with Planck+WP data fits better to the line of sight measurement $H(z = 2.34) = 222 \pm 7$ km/s/Mpc, but only at the expense of still having a poor fit to the BAO transverse measurements.

V.C. Kuriakose

Entropy spectrum of (1 + 1) dimensional stringy black holes

We explore the entropy spectrum of (1 + 1) dimensional dilatonic stringy black holes via the adiabatic invariant integral method known as Jiang and Hans method [Phys. Lett. B, **718**, 584 (2012)] and the Bohr Sommerfeld quantization rule. It is found that the corresponding spectrum depends on black hole parameters like charge, ADM mass, and more interestingly, on the dilatonic field. We calculate the entropy of the present black hole system via the Euclidean treatment of quantum gravity and study the thermodynamics of the black hole and find that the system does not undergo any phase transition. This work has been done collaboration with Jishnu Suresh.

Phase transitions and geometrothermodynamics of regular black holes

We study the thermodynamics and state space geometry of a set of regular black hole solutions such as Bardeen (1968), Ayn-Beato and Garca (Phys Rev Lett 80, 5056, 1998), Hayward black hole (Phys. Rev. Lett. **96**, 031103, 2006) and Berej Matyjasek Trynieki Wornowicz (Gen Rel. Grav., **38(5)**,885906, 2006). We find that all these black holes show second order thermodynamic phase transitions by observing discontinuities in heat capacity entropy graphs as well as the cusp type double point in free energy temperature graph. Using the formulation of geometro-thermodynamics, we again find the singularities in the heat capacity of the black holes by calculating the curvature scalar of the Legendre invariant metric. This work has been done in collaboration with R. Tharanath and Jishnu Suresh.

Badam Singh Kushvah

Orbital dynamics of exoplanetary systems Kepler-62, HD 200964 and Kepler-11

The presence of mean-motion resonances (MMRs) in exoplanetary systems is a new exciting field of celestial mechanics, which motivates us to consider this work to study the dynamical behaviour of exoplanetary systems by time evolution of the orbital elements of the planets. Mainly, we study the influence of planetary perturbations on semi-major axis and eccentricity. We identify $(r+1):r$ MMR terms in the expression of disturbing function and obtain the perturbations from the truncated disturbing function. Using the expansion and an analytical approach, we solve the equations of motion. The solution, which is obtained analytically is compared with that of numerical method to validate our analytical result. In this work, we consider three exoplanetary systems namely Kepler-62, HD 200964 and Kepler-11. We have plotted the evolution of the resonant angles and found that they librate around constant value. In view of this, we conclude that two planets of each system Kepler-62, HD 200964 and Kepler-11 are in 2:1, 4:3 and 5:4 mean motion resonances, respectively. This work has been collaboration with Rajib Mia.

Irom Ablu Meitei

Quantum radiation of Maxwell's electromagnetic field in non-stationary Kerr-de Sitter black hole

Quantum thermal and non-thermal radiations are important aspects in the study of black hole physics. In this work, we have used the generalised tortoise coordinate transformation to reduce Klein-Gordon equation of a scalar particle and Maxwell's electromagnetic field equations in non-stationary Kerr-de Sitter spacetime into a combined form of wave equation. The Hawking temperature and chemical potential are recovered from the thermal radiation spectra. An extra coupling effect is observed to be present in the thermal radiation spectrum of Maxwell's electromagnetic field equations, which is not present in the thermal radiation spectrum of scalar particles.

We also investigate the quantum non-thermal radiation of non-stationary Kerr-de Sitter black hole using Hamilton-Jacobi equation. It is shown that there exist seas of positive and negative energy states separated by a forbidden energy gap. In the vicinity of the event horizon, the width of the forbidden energy gap tends to zero, showing that there is crossing of positive and negative energy levels near the event horizon. The chemical potential derived from the thermal radiation spectrum of scalar particles is found to be equal to the highest energy of the negative energy state of the scalar particles in non-thermal radiation. This work has been done in collaboration with T. Ibungochouba Singh and K. Yugindro Singh.

Hawking radiation as tunnelling of vector particles from Kerr-Newman black hole

In this work, by applying the WKB approximation and Hamilton-Jacobi ansatz to the Proca equation, we investigate the tunnelling of vector Bosons across the event horizon of Kerr-Newman black hole and also the resulting vector particles' Hawking radiation. The tunnelling probability of the vector particles is determined using the imaginary part of the action of the emitted particles. Universality of the properties of the emitted spectra of different types of particles is established for Kerr-Newman black hole.

The coordinate problem for Hawking radiation of the vector particles is investigated using three coordinate systems, namely, naive, Painleve and Eddington. The thermal spectrum of the radiated vector Bosons has been determined using direct computation corresponds to a temperature, which is twice the Hawking temperature of Kerr-Newman black hole for scalar particles. If well behaved Eddington and Painleve coordinates are used, then the correct result of Hawking temperature is obtained. The reason for the discrepancy in the results of the naive coordinate and well behaved coordinates is also discussed. The work has been done in collaboration with T. Ibungochouba Singh and K. Yugindro Singh.

Hameeda Mir

Clustering of galaxies in brane world models

In this work, we analyze the clustering of galaxies using a modified Newtonian potential. This occurs due to the existence of extra dimensions in brane world models, and we analyze a system of galaxies interacting with each other. The partition function for this system of galaxies has been be calculated, and this function is used to calculate the free energy of this system of galaxies. The entropy and the chemical potential for this system has also been calculated. We have derived an explicit expression for the clustering parameter, and this parameter will determine the behaviour of this system, and we are able to express various thermodynamic quantities using this clustering parameter. We also analyze the effect of extra dimensions on the two-point functions between galaxies. This work has been done in collaboration with Mir Faizal and Ahmad Farag Al.

Hemwati Nandan

Geodesic motion in R-charged black hole spacetimes

We study the geodesic motion of massive and massless test particles in the background of a particular class of multiple charge black holes in gauged supergravity theories in $D = 4$. We have analysed the horizon structure along with the nature of the effective potentials for the case of four equal charges. In view of the corresponding effective potentials, we have discussed all the possible orbits in detail for different values of energy and angular momentum of the incoming test particles. The periods for one complete revolution of circular orbits and the advance of perihelion of the planetary orbit have also been investigated in greater detail for massive test particles. We have also discussed the time period of unstable circular motion and cone of avoidance of massless test particles in detail. All the corresponding results obtained for massive and massless test particles are then compared accordingly. This work has been done in collaboration with Rashmi Uniyal, Anindya Biswas and K. D. Purohit.

Null geodesics in a magnetically charged stringy black hole spacetime

We study the null geodesics of a four-dimensional magnetic charged black hole spacetime arising in string theory. The behaviour of effective potential in view of the different values of black hole parameters are analysed in the equatorial plane, and the possible orbits for null geodesics are also discussed. We have also calculated the frequency shift of photons in this spacetime. The results are compared to those obtained for the electrically charged stringy black hole spacetime and the Schwarzschild black hole spacetime.

Biswajit Pandey

Testing homogeneity in the Sloan Digital Sky Survey Data Release Twelve with Shannon entropy

The statistical homogeneity and isotropy of the Universe on sufficiently large scales is a fundamental assumption in modern cosmology. One cannot derive this principle in a strictly mathematical sense and can only verify this by analyzing various cosmological observations and comparing them with the theoretical predictions based on it. We use Shannon entropy as a measure of non-uniformity or inhomogeneity to test the cosmological principle in the Sloan Digital Sky Survey Data Release Twelve (SDSS DR12). We analyze a set of volume limited samples to quantify the degree of inhomogeneity at different length scales. We find that the galaxy distributions exhibit a higher degree of inhomogeneity as compared to a Poisson point process at all length scales. Our analysis indicates that signatures of inhomogeneities in the galaxy distributions persist at least upto a length scale of $120\,h^{-1}\,\mathrm{Mpc}$. The galaxy distributions appear to be homogeneous on a scale of $140\,h^{-1}\,\mathrm{Mpc}$ and beyond. Analyzing a set of mock galaxy samples from a semi-analytic galaxy catalogue from the Millennium simulation, we find that there is a scale of transition to homogeneity at $\sim 100\,h^{-1}\,\mathrm{Mpc}$. This work has been done in collaboration with Suman Sarkar.

S. K. Pandey

Multi-wavelength study of a sample of radio loud galaxies

Optical BVR and Hα data obtained using 2 m IGO telescope at Girawali, and 2 m HCT IAO Hanle, and archival multi-band data from SDSS (ugriz), 2MASS (JHKs), WISE, Spitzer (mid-IR), XMM, Chandra (X-ray), UV (GALEX), and radio from VLA, IRAM were collected for the sample galaxies. Standard techniques of surface photometry were used to derive surface brightness profiles and profiles of geometrical parameters, such as ellipticity, position angle, etc. The surface brightness profiles were fitted to the core-Sersic model for the quantification of the radial stellar distributions of the sample galaxies. The multiband colour index profiles, e.g., u-g, g-r, r-i, i-z, B-R, B-V, J-Hs , J-Ks , H-Ks , R-Ks , 3.4 - 4.6μm , 4.6 - 12 μm (mid-IR) and FUV-NUV were used in combination with unsharp-masked images, residual maps, quotient maps, dust extinction maps, Hα emission maps, CO intensity maps, diffuse X-ray emission maps of the galaxies with a view to study the morphology, properties and physical correlations of different phases (e.g., cool gas, dust, ionized gas, and hot gases) of ISM as well as to examine star formation processes in the sample galaxies. This work has been done in collaboration with his research student, Sheetal Sahu.

Study of accretion process and jets in X-ray binaries

This work is focused on Stellar Mass Black Hole binary GX339-4. For this source, RXTE database archive spanning the period 1997 - 2012 were collected. During this period, the source has shown 5 outbursts. A systematic analysis of low/hard state RXTE spectra of GX339-4 may possibly help in constraining the geometry of the system. One of the popular models for the low/hard state for black hole binaries is that the standard accretion disk is truncated and the hot inner region produces hard X-ray flux, via Comptonization. On the other hand, the suggestive presence of a broad Iron line during the hard state would indicate that the accretion disk is not truncated but extends all the way to the inner most stable orbit. In such a case, it is puzzling as to why the hot medium would remain photon starved. The broad Iron line should be accompanied by a broad smeared reflection bump at $\sim$ 30 keV, and it may be that this additional component makes the spectrum hard, and the intrinsic photon index is ¿ 2. This would mean that the medium is not photon deficient, reconciling the presence of a broad Iron line in the hard state. To test this hypothesis, it proposed to analyze the RXTE observations of GX 339-4 during the 2002 - 2003 outburst, and identify the observations when the system was in the hard state and showed a broad Iron line. This work has been done in collaboration with his research student Kalyani Bagri, and J.S. Yadav and Ranjeev Misra.

P.N. Pandita

Renormalization group invariants and sum rules in the deflected mirage mediation super-symmetry breaking

We examine the deflected mirage mediation super-symmetry breaking (DMMSB) scenario, which combnes three super-symmetry breaking scenarios, namely, anomaly mediation, gravity mediation and gauge mediation, using the one-loop renormalization group invariants (RGIs). We analyse the effects on the RGIs at the threshold where the gauge messengers emerge, and derive the super-symmetry breaking parameters in terms of the RGIs. We further discuss whether super-symmetry breaking mediation mechanism can be determined using a limited set of invariants, and derive sum rules valid for DMMSB below the gauge messenger scale. In addition, we examine the implications of the measured Higgs mass for the DMMSB spectrum. This work has been done in collaboration with Katri Huitu and Paavo Tiitola.

Invisible decays of the heavier Higgs Boson in the minimal super-symmetric standard model

We consider the possibility that the heavier CP-even Higgs Boson (H^0) in the minimal super-symmetric standard model (MSSM) decays invisibly into neutralinos in the light of the recent discovery of the 126 GeV resonance at the CERN Large Hadron Collider (LHC). For this purpose, we consider the minimal super-symmetric standard model with universal, non-universal and arbitrary boundary conditions on the super-symmetry breaking gaugino mass parameters at the grand unified scale. Typically, scenarios with universal and non-universal gaugino masses do not allow invisible decays of the lightest Higgs Boson, which is identified with the 126 GeV resonance, into the lightest neutralinos in the MSSM. With arbitrary gaugino masses at the grand unified scale, such an invisible decay is possible. The second lightest Higgs Boson can decay into various invisible final states for a considerable region of the MSSM parameter space with arbitrary gaugino masses as well as with the gaugino masses restricted by universal and non-universal boundary conditions at the grand unified scale. The heavier Higgs Boson decay into lighter particles leads to the intriguing possibility that the entire Higgs Boson spectrum of the MSSM may be visible at the LHC even if it decays invisibly, during the searches for an extended Higgs Boson sector at the LHC. In such a scenario, the non-observation of the extended Higgs sector of the MSSM may carefully be used to rule out regions of the MSSM parameter space at the LHC. This work has been done in collaboration with B. Anantha narayanan and Jayita Lahari.

Amit Pathak

Theoretical study of deuteronated PAHs as carriers for IR emission features in the ISM

This work proposes deuteronated PAH ($DPAH^+$) molecules as a potential carrier of the 4.4 and 4.65 μm mid infrared emission bands that have been observationally detected towards the Orion and M17 regions. Density Functional Theory calculations have been carried out on $DPAH^+$ molecules to see the variations in the spectral behaviour from that of a pure PAH. $DPAH^+$ molecules show features that arise due to the stretching of the aliphatic C-D bond. Deuterated PAHs have been previously reported as carriers for such features. However, preferred conditions of ionization of PAHs in the interstellar medium (ISM) indicates the possibility of the formation of $DPAH^+$ molecules. Comparison of band positions of $DPAH^+$s shows reasonable agreement with the observations. We report the effect of size of the $DPAH^+$ molecules on band positions and intensities. This study also reports a D/H ratio ($[D/H]_{sc}$; the ratio of $C-D$ stretch and $C-H$ stretch bands per $[D/H]_{num}$) that is decreasing with the increasing size of $DPAH^+$s. It is noted that large $DPAH^+$ molecules (no. of C atoms ~ 50) match the D/H ratio that has been estimated from observations. This ratio offers prospects to study the deuterium abundance and depletion in the ISM. This work has been done in collaboration with M. Burgohain, P. J. Sarre, T. Onaka and I. Sakon.

FUSE view of Interstellar OVI

Far-Ultraviolet Spectroscopic Explorer (*FUSE*) telescope has played an important role in the study of interstellar OVI. Here we present a brief review of the distribution and some of the properties of OVI in the Milky Way (MW) and in the nearby galaxies; the Large Magellanic Cloud (LMC) and the Small Magellanic Cloud (SMC) as found by different *FUSE* observations. The distribution of OVI throughout the Galaxy and in the LMC and the SMC is patchy. OVI column density has been found to vary on a very small scale. There are variations in the OVI content of the northern hemisphere compared to the southern hemisphere of the Milky Way. Surprisingly, despite being of lower metallicity, the OVI column density in the SMC has been found to be higher compared to the Milky Way and the LMC. This work has been done in collaboration with R. Sarma and J. K. Sarma.

Madhav K. Patil

X-ray cavities and temperature jumps in the environment of strong cool core cluster Abell 2390

We present results based on the systematic analysis of high resolution 95 ks Chandra observations of the strong cool core cluster Abell 2390 at the redshift of $z = 0.228$ that hosts an energetic radio AGN. This analysis has enabled us to investigate five X-ray deficient cavities in the central 30 arcsec region of the atmosphere of Abell 2390. Presence of these cavities has been confirmed through a variety of image processing techniques like, the surface brightness profiles, unsharp masked image, as well as 2D elliptical model subtracted residual map. Temperature profile as well as 2D temperature map derived from the contour binning technique revealed structures in the distribution of ICM, in the sense that ICM in the north-west direction is cooler than that on the south-east direction. Temperature jump evident at 25 arcsec (90.5 kpc) corresponds to the Mach number $\sim 1.44 \pm 0.05$, while that at 68 arcsec (246 kpc) along the north-west direction exhibits jump from 7.47 keV to 9.10 keV and corresponds to the Mach number 1.22 ± 0.06. Both these jumps are associated with the cold fronts. Tricolour map as well as hardness ratio map detect cool gas clumps in the central 30 kpc region of temperature $4.45^{+0.16}_{-0.10}$ keV.

The entropy profile derived from the X-ray spectral analysis is found to fall systematically inward in a power-law fashion and exhibits a floor near 12.20±2.54 keV cm^2 in the central region. This flattening of the entropy profile in the core region confirms the intermittent heating of the ICM by the AGN feedback. The diffuse radio emission map at 1.4 GHz using VLA L-band data exhibits highly asymmetric morphology with an edge in the north-west direction coinciding with the X-ray edge seen in the unsharp mask image. The mechanical power injected by the AGN in the form of X-ray cavities is found to be 5.94×10^{45} erg s^{-1} and is roughly an order of magnitude higher than the energy lost by the ICM in the form of X-ray emission, confirming that AGN feedback is capable enough to quench the cooling flow in this cluster. This work has been done in collaboration with S. S. Sonkamble and Nilkanth D. Vagshette.

X-Ray emission from a prominent dust lane lenticular galaxy NGC 5866

We report the multi-band imagery with an emphasis on the X-ray emission properties of a prominent dust lane lenticular galaxy NGC 5866. X-ray emission from this galaxy is due to a diffuse component and a substantial contribution from the population of discrete X-ray binary sources. A total of 22 discrete sources have been detected within the optical D_{25} extent of the galaxy, a few of which exhibit spatial association with the globular clusters hosted by this system. Composite spectrum of the diffuse emission was well constrained by a thermal plasma model plus a power law component to represent the emission from unresolved sources, while that of the discrete sources was well fitted by an absorbed power law component of photon index $\Gamma \sim 1.82\pm0.14$. X-ray colour-colour plot for the resolved source was used to classify the detected sources. The cumulative X-ray luminosity function of the XRBs is well represented by a power law function of index of $\Gamma \sim 0.82\pm0.12$. Optical imagery of NGC 5866 revealed a prominent dust lane along the optical major axis of the host with dust extinction properties similar to those of the canonical grains in the Milky Way. The dust grains responsible for the extinction of star light in NGC 5866 are relatively smaller in size when compared with the canonical grains in the Milky Way and high energetic charged particles seems to be responsible for the modulation of the dust grain size. Spatial correspondence is evident between the dust and other phases of ISM. This work has aslo been done in collaboration with Nilkanth D. Vagshette and S. S. Sonkamble.

Bikas Chandra Paul

Dissipative gravitational collasse of an isotropie star

A theoretical framework is developed to study the effects of pressure anisotropy on the evolution of a collapsing star dissipating energy in the form of radial heat flux. In this construction, the star begins its collapse from an initial static configuration described by Paul and Deb [Ap. Space Sci., **354**, 421 (2014)] solution in the presence (or absence) of anisotropic stresses. The form of the initial static solution, which is a generalization of Pant and Sah [Phys. Rev. D, **32**, 1538 (1985)] model, complies with all the requirements of a realistic star and provides a simple method to analyze the impacts of anisotropy onto the collapse. This work has been done in collaboration with S. Das, R. Sharma and R. Deb.

Constraining modified Chaplgin gas parameters

Evolution of the universe with modified Chaplygin gas (MCG) described by the equation of state $p = A\rho - \frac{B}{\rho^{\alpha}}$ where A and B are constants is investigated. Using the observed data, constraint on the free parameters of MCG is determined. We note that in such a scenario, A flip of the sign of the deceleration parameter leading to a transition from deceleration to acceleration is found. Stability of the cosmological model against the density perturbation is also studied in some detail, and it is found that the effective acoustic speed may become imaginary depending on the initial data, a signal that perturbations associated with instability set in, resulting in structure formation. As one considers more negative values of A, the flip in sign is delayed making the density parameter change fast. Again, it is found from the contour plot that compatibility with observational data is admitted with a value of A , which is very near to zero or a small negative number. This work has been done in collaboration with D. Panigrahi and S. Chatterji.

Surajit Paul

Uniqueness of galaxy groups in the structural hierarchy from its radio signature

Galaxy groups, being the intermediate structures between the field galaxies and the clusters of galaxies, are a very important part of cosmological structures. We modelled their energetics using cosmological simulations (with ENZO 2.1 code) and also implemented them on observed SDSS galaxy groups to compute radio and X-ray emissions. Our study establishes uniqueness of energetics of the groups in the structural hierarchy. This study has been done in collaboration with Prateek Gupta, Reju Sam and Venkat Punjabi.

Ninan Sajeeth Philip

Study on the obsuring dust torus of type 1 AGN

The unification scheme of active galactic nuclei proposes the presence of a dusty torus around the central source. According to this model the obscuring torus is responsible for the differences between the AGN spectral energy distributions that depends on the viewing angles with respect to the line-of- sight. It is assumed that a fraction of the AGN luminosity is absorbed by the dusty torus and re-radiated in the infrared band. Thus, the fraction of the sky seen from the centre of the AGN, known as the covering factor, can be obtained from the ratio of the IR to the bolometric luminosities of the source. However, because of the difficulty in determining the bolometric luminosities, the estimation of the covering factor cannot be accurately determined for most of the AGN sources. Furthermore, the interstellar medium in our Galaxy absorbs UV radiation emitted close to the peak of the SEDs in AGN. The covering factors of X-ray/optically selected sample of 51 type 1 AGNs is studied. The IR and bolometric luminosities were estimated by analysing the broad-band (IR - X-ray) SEDs of the sample using the SDSS, XMM-Newton, WISE, 2MASS and UKIDSS data. A self consistent energy conserving model was used to include the important contribution in the unobservable far-UV region. The study has found that the covering factor is dependent on both the bolometric luminosity and the Eddington ratio of the AGN sample. We have continued to understand the exact nature of this correlation as it is known that the covering factor is inversely related to the bolometric luminosity. This study is done by taking random values for bolometric and IR luminosities from uniform distributions in the same range obtained in the previous study to check for the rank of correlations of the distributions for 10,000 realizations. This work has been done in collaboration with Savithri H. Ezhikode, Gulab C. Dewangan, Ranjeev Misra, Shruti Tripathi and Ajit K. Kembhavi.

Anirudh Pradhan

Unifying inflation and late-time acceleration in a BIonic system

We propose a cosmological model that unifies inflation, deceleration and acceleration phases of expansion history by a BIonic system. At the beginning, there are k black fundamental strings that transited to the BIon configuration at a given corresponding point. Here, two coupled universes, brane and anti-brane, are created interacting each other through a wormhole and inflate. With decreasing temperature, the energy of this wormhole flows into the universe branes and lead to inflation. After a short time, the wormhole evaporates, the inflation ends and a deceleration epoch starts. By approaching the brane and anti-brane universes together, a tachyon is born, grows and causes the creation of a new wormhole. At this time, the brane and anti-brane universes result connected again and the late-time acceleration era of the universe begins. We compare our model with previous unified phantom models and observational data obtaining some cosmological parameters like temperature in terms of time. We also find that deceleration parameter is negative during inflation and late-time acceleration epochs, while it is positive during the deceleration era. This means that the model is consistent, in principle, with cosmological observations. This has been proposed in collaboration with Alireza Sepehri, Farook Rahaman, M. R. Setare, S. Capozziello and I. H. Sardar.

$F(R)$ bouncing cosmology with future singularity in brane-anti-brane system

Recently, Odintsov and Oikonomou [Phys. Rev. D, **92**, 024016 (2015)] proposed Type IV singular bounce in a modified gravity and found an explicit form of $F(R)$, which can generate this type of bouncing cosmological evolution. In this work, we construct their model in string theory and show that interaction between branes is the main cause of $F(R)$ bouncing cosmology. In our technique, N fundamental strings decay first to N $M0$-anti-$M0$-brane then, $M0$-branes link to each other, originate and form an $M3$-anti-$M3$ system. Our universe is located on one of these $M3$-branes and interact with the universe on another $M3$-brane via some scalars. The branes in this system wrap around each other and form a compact system. This process causes to a contraction of universes. Also, the relevant actions of compacted $M3$-branes include higher order of derivatives, which lead to communication relations in generalized uncertainty principle. On the other hand, branes and anti-branes absorb each other, the radius of compactification is reduced, some of the scalars gain negative square masses and become tachyons. This system is unstable, broken and branes rebound to non-compact state during an expansion branch. With opening of branes, some other scalars achieve to tachyon phase and consequently, this epoch stops. This process may be repeated in different branches. In this theory, the Type IV singularity occurs at $t = t_s$, which is the time of producing tachyons between two branches. It is observed that the derived model is in good agreement with recent Planck data [Ade et al. in arXiv:1502.02114[astro-ph.CO] and arXiv:1303.5082[astro-ph.CO] and obtain the bouncing point. This work has been done in collaboration with Alireza Sepehri and Somayyeh Shoorvazi.

Farook Rahaman

Could wormholes form in dark matter galactic halos?

We estimate expression for velocity as a function of the radial coordinate r by using polynomial interpolation based on the experimental data of rotational velocities at distant outer regions of galaxies. The interpolation technique has been used to estimate fifth degree polynomial followed by cubic spline interpolation. This rotational velocity is used to find the geometry of galactic halo regions within the framework of Einstein's general relativity. In this work, we have analyzed features of galactic halo regions based on two possible choices for the dark matter density prole, viz. Navarro, Frenk and White type (1996), and Universal Rotation Curve (URC) (Castignani et al. 2012) It is argued that spacetime of the galactic halo possesses some of the characteristics needed to support traversable wormholes. This work has been done in collaboration with Banashree Sen, Gopal Chandra Shit and Saibal Ray.

Simultaneous emergence of curved spacetime and quantum

We have shown that the geometrically structureless spacetime manifold is converted instantaneously to a curved one, the Riemannian or may be a Finslerian spacetime with an associated Riemannian spacetime, on the appearance of quantum Weyl spinors dependent only on time in that background at manifold and having the symplectic property in the abstract space of spinors. The scenario depicts simultaneous emergence of the gravity in accord with general relativity and quantum mechanics. The emergent gravity leads to the generalized uncertainty principle, which in turn, ushers in discrete spacetime. The emerged spacetime is specified here as to be Finslerian and the field equation in that spacetime has been obtained from the classical one due to the arising quantized space and time. From this we find the quantum field equation for highly massive (of the Planck order) spinors in the associated Riemannian space of the Finsler space, which is in fact, the background homogeneous and isotropic FRW spacetime of the universe. These highly massive spinors provide the mass distribution complying Einstein equivalence principle. All these occurred in the indivisible minimum time considered as zero time or spontaneity. This work has been done in collaboration with S. S. De.

Saibal Ray

Spherically symmetric charged compact stars

We consider the static spherically symmetric spacetime metric of embedding class one. Specifically three new electromagnetic mass models are derived, where the solutions are entirely dependent on the electromagnetic field, such that the physical parameters like, density, pressure, etc. do vanish for the vanishing charge. We have analyzed schematically all these three sets of solutions related to electromagnetic mass models by plotting graphs and shown that they can pass through all the physical tests. To validate these special type of solutions related to electromagnetic mass models, a comparison has been done with that of compact stars and shown exclusively the feasibility of the models. This work has been done in collaboration with S. K. Maurya, Y. K. Gupta and S. Roy Chowdhury.

Anisotropic stars with non-static conformal symmetry

We propose a model for relativistic compact star with anisotropy, and analytically obtain exact spherically symmetric solutions describing the interior of the dense star admitting non-static conformal symmetry. Several features of the solutions including drawbacks of the model have been explored and discussed. For this purpose, we have provided the energy conditions, TOV-equations and other physical requirements and thus, thoroughly investigated stability, mass-radius relation and surface redshift of the model. It is observed that most of the features are well matched with the compact stars, like quark/strange stars. This work has been done in collaboration with D. Shee, Farook Rahaman and B. K. Guha.

Anirban Saha

On the Landau system in non-commutative phase-space

We consider the Landau system in a canonically non-commutative phase-space. A set of generalized transformations containing scaling parameters are derived, which maps the NC problem to an equivalent commutative problem. The energy spectrum admits NC corrections, which are computed using the explicit NC variables as well as the commutative-equivalent variables. Their exact matching solidifies the evidence of the equivalence of the two approaches. We also obtain the magnetic length and level degeneracy, which admit NC corrections. We further study the AharonovBohm effect, where the phase-shift is found to alter due to non-commutativity and also depends on the scaling parameters.

Sanjay Kumar Sahay

Grouping the executables to detect malware with high accuracy

The metamorphic malware variants with the same malicious behaviour (family), can obfuscate themselves to look different from each other. This variation in structure lead to a huge signature database for traditional matching techniques to detect them. In order for effective and efficient detection of malware in large amounts of executables, we need to partition these files into groups which can identify their respective families. In addition, the grouping criteria should be chosen such a way that, it can also be applied to unknown files encounter on computer for classification. This work discusses the study of malware and benign executables in groups to detect unknown malware with high accuracy. We have studied sizes of malware generated by three popular second generation malware (metamorphic malware) creator kits, viz. G2, PS-MPC and NGVCK, and observed that the size variation in any two generated malware from same kit is not much. Hence we have grouped the executables on the basis of malware sizes by using Optimal k-Means Clustering algorithm and used these obtained groups to select promising features for training (Random forest, J48, LMT, FT and NBT) classifiers to detect variants of malware or unknown malware. We find that detection of malware on the basis of their respected file sizes gives accuracy up to 99.11% from the classifiers. This work has been done in collaboration with Ashu Sharma.

Extreme learning machines in the field of text classification

In order to speed-up and further improve tasks like information search and retrieval, personalization, etc., it is highly important to develop techniques to classify text documents more accurately and efficiently than before. This work is an effort in that direction, where the effectiveness of Extreme Learning Machines (ELM) in the domain of text classification is studied and compared with many of the existing relevant techniques like Support Vector Machines (SVM), which are currently one of the most popular and effective techniques for classifying text documents. Ours is one of the few works that highlight the high performance of ELM in the field of text classification, by implementing classifiers based on different interpretations of ELM, analyzing their performance, and studying which feature selection techniques are most suited to improve their accuracy. In our multi-class classification problem, we have studied a single ELM classifier based on the one-against-all scheme, and a multi-layer ELM classifier inspired from deep networks, and then perform extensive experiments on different datasets to demonstrate the applicability and effectiveness. Results show that ELM based classifiers can outperform many of the traditional classification techniques including the most powerful state-of-the-art technique such as SVM. This work has been done in collaboration with R. K. Roul, Ashish Nanda and Viraj Patel.

Sanjay Baburao Sarwe

Linear isentropic equation of state in formation of black hole and naked singularity

We analyse the physical process of gravitational collapse of a spherically symmetric perfect fluid spacetime with a linear isentropic equation of state p = kp. We propose two models, with ansatzes that give rise to a family of solutions to Einstein equations with equation of state which evolves from a regular initial data satisfying weak energy conditions. The model with first ansatzleads to homogeneous collapse that terminates into the formation of black hole. We establish that as the parameter $k \rightarrow 1$in the range -1/3 $\leq k \leq 1$, the formation of black hole gets accelerated in time, revealingthe significance of equation of state in black hole formation. In the second model, the end state of collapse in marginally bound space-time is investigated in the range $0 < k \leq 1$. It is shown that the inhomogeneous collapse culminates into formation of black hole andnaked singularity, and that solely depends on the generic regular initial data and the role played by the pressure through parameter k. These studies give us deeper insights into the final states of collapse with aphysically relevant equation of state in the light of cosmic censorship conjecture.

Asoke Kumar Sen

Trajectory of a light ray in Kerr field: Determined using a material medium approach

The deflection of light ray as it passes around a gravitational mass can be calculated by different methods. Such calculations are generally done by using the null geodesics under both strong field and weak field approximation. However, several authors have studied the gravitational deflection of light ray using material medium approach. For a static, non-rotating spherical mass, one can determine the deflection in Schwarzschild field, by expressing the line element in an isotropic form and calculating the refractive index to determine the trajectory of the light ray. In this work, we draw attention to the refractive index of light ray in Kerr field using the material medium approach. The frame dragging effects in Kerr field is considered to calculate the velocity of light ray and finally the refractive index. Hence, the deflection of light ray is calculated, assuming far field approximation and compared the results with those calculations done earlier using null geodesics. This work has been done in collaboration with S. Roy.

Laboratory light scattering from regolith surface and simulation of data by Hapke model

The small atmosphereless objects of our solar system, such as asteroids and the moon, are covered by layer of dust particles known as regolith, formed by meteoritic impact. The light scattering studies of such dust layer by laboratory experiment and numerical simulation are two important tools to investigate their physical properties. In the laboratory of the Department of Physics, Assam University, the light scattered from a layer of dust particles, containing 0.3 μm Al_2O_3 at wavelength 632.8 nm, has been analysed, and has been was performed by using a light scattering instrument ellipsometer. Through this experiment, the photometric and polarimetric phase curves of light scattered from such a layer have been generated. In order to numerically simulate this data, Hapke's model combined with Mie's single particle scattering properties is used. The perpendicular and parallel components of single particle albedo and the phase function are derived from Mie theory. By using Hapke's model combined with Mie theory, the physical properties of the dust grain such as grain size, optical constant (n, k) and wavelength can be studied through this scheme. In the literature, till today no theoretical model to represent polarisation caused due to scattering from rough surface is available, which can successfully explain the scattering process. So the main objective of the reported work has been to develop a model which can theoretically estimate polarisation as caused due to scattering from rough surface and also to validate the proposed model with the laboratory data generated in the present work. This work has been done in collaboration S. Dev.

T.R. Seshadri

The origin of seed magnetic field over large scale using higher dimensional cosmology

If the origin of seed magnetic field over large scales is primordial, it could be produced during inflation. This, however, requires breaking of confirmed invariance of the electromagnetic Lagrangian. Usually this is achieved by an adhoc mechanism. We have investigated this using higher dimensional cosmology, where this breaking of conformal invariance is achieved in a natural way. We have also investigated the generation of helical magnetic fields by this procedure. This work has been done in collaboration with Kumar Atmjeet, Isha Pahwa and Kandaswamy Subramanian.

Clustering properties of H1 clouds

Neutral hydrogen can potentially be detected using 21 cm emission. Thus, the spatial distribution of 21 cm emission can shed light on the clustering properties of H1 clouds. This is potentially a very useful study in the context of SKA. Presently, we are studying this by applying the technique on simulations. Once the techniques are sharpened, they can be readily used as and when data becomes available. This work has been done in collaboration with Bidisha and Tirthankar Roy Choudhury.

Ranjan Sharma

Gravitational collapse in spatially isotropic coordinates

To investigate the nature of dissipative gravitational collapse, the author and his collaborators (Megandhren Govender, Robert Bogadi and Shyam Das) have developed a dynamical model of a self-gravitating star from the static spherically symmetric stellar solution of Pant and Sah [Phys. Rev. D, **32**, 1358 (1985)]. The model has been developed by allowing a constant parameter in the static model to evolve with time. The resulting dynamical model is a radiating collapsing star with heat conduction enveloped by a radiation atmosphere. In the construction, the collapse begins from a physically acceptable initial stage and is found to proceed without formation of an event horizon. The model provides snapshots of the collapse process, particularly during the late stages of its evolution just before the formation of the remnant. Thermodynamic analysis of the collapsing star within the framework of extended irreversible thermodynamics reveals the significance of relaxational effects on the physical characteristics (such as temperature) of the collapsing system.

Gravitational collapse of a circularly symmetric star in an anti-de Sitter spacetime

One of the most fundamental problems in general relativity is the successful prediction of the final stage of a gravitationally collapsing system. In the context of Cosmic Censorship Conjecture (CCC), investigation of collapsing systems has become extremely fascinating with the discovery of a black hole solution in $(2 + 1)$-dimensions by Bañados, Teitelboim and Zanelli (BTZ). The author and his collaborators (Shyam Das, Farook Rahaman and Gopal Chandra Shit) have developed a model of a circularly symmetric collapsing star with outgoing radiation in an anti-de Sitter spacetime. The exterior spacetime of the collapsing star has been assumed to be described by the non-static generalisation of the BTZ metric [*Phys. Rev. Lett.*, **69** (1992) 1849]. Making use of the junction conditions joining the interior and the exterior spacetimes smoothly across the boundary,we have investigated the impacts of various factors on the evolution of the star. Depending on initial conditions, two possible outcomes of the collapse process have been shown: (i) formation of a BTZ black hole, and (ii) evaporation of all mass-energy even before the singularity is reached. The investigation brings out the role of initial conditions on the evolution of a circularly symmetric collapsing matter in the presence of radiation.

Harinder Pal Singh

The evolution of disc galaxies with and without classical bulges since $z \sim 1$

Establishing the relative role of internally and externally driven mechanisms responsible for disc and bulge growth is essential to understand the evolution of disc galaxies. In this context, we have studied (with Sonali Sachdeva, Kanak Saha and D. Godotti) the physical properties of disc galaxies without classical bulges in comparison to those with classical bulges since $z \sim 0.9$. Using images from the Hubble Space Telescope and Sloan Digital Sky Survey, we have computed both parametric and non-parametric measures, and examined the evolution in size, concentration, stellar mass, effective stellar mass density and asymmetry. We find that both disc galaxies with and without classical bulges have gained more than 50% of their present stellar mass over the last $\sim$ 8 Gyrs. Also, the increase in disc size is found to be peripheral. While the average total (Petrosian) radius almost doubles from z $\sim$ 0.9 to z $\sim$ 0, the average effective radius undergoes a marginal increase in comparison. Additionally, increase in the density of the inner region is evident through the evolution of both concentration and effective stellar mass density. We find that the asymmetry index falls from higher to lower redshifts, but this is more pronounced for the bulgeless disc sample. Also, asymmetry correlates with the global effective radius, and concentration correlates with the global Sersic index, but better so for higher redshifts only. The substantial increase in mass and size indicates that accretion of external material has been a dominant mode of galaxy growth, where the circumgalactic environment plays a significant role

Large Magellanic Cloud near-infrared synoptic survey

Under an Indo-US collaboration, we present new near-infrared Cepheid Period-Wesenheit relations in the LMC using time-series observations from the Large Magellanic Cloud near-infrared synoptic survey. We also derive optical+near-infrared P-W relations using V and I magnitudes from OGLE-III. We employ our new JHKs CPAPIR data to determine an independent distance to the LMC of μLMC=18.47±0.07 (statistical) mag, using an absolute calibration of the galactic relations based on several distance determination methods and accounting for the intrinsic scatter of each technique. We also derive new near-infrared Period-Luminosity and Wesenheit relations for Cepheids in M31 using observations from the PHAT survey. We use the absolute calibrations of the galactic and LMC W(J,H) relations to determine the distance modulus of M31, μM31=24.460±20~mag. We apply a simultaneous fit to Cepheids in several local group galaxies covering a range of metallicities ($7.7 < 12 + log[O/H] < 8.6 \sim$ dex) to determine a global slope of -3.244±0.016~mag/dex for the W(J,Ks) relation and obtain robust distance estimates. Our distances are in good agreement with recent TRGB based distance estimates and we do not find any evidence for a metallicity dependence in the near-infrared P-W relations. This work has been done in collaboration with A. Bharadwaj, S. M. Kanbur, L. N. Marcri, C.C. Ngeow et. at.

K. Sriram

A study of the dynamical cross correlation function in a black hole source XTE J1550-564

The short time scale X-ray variability associated with the accretion disk around compact objects is complex and is vaguely understood. The study of the cross correlation function gives an insight into the energy dependent behaviour of the variations and hence connected processes. Using high resolution RXTE data, we investigate the dynamical cross correlation function of an observation of a black hole source XTE J1550-564 in the steep power law state. The cross correlation between soft and hard X-ray energy bands revealed both correlated and anti-correlated delays ($\pm 15s$) on a correlation time scale of 50 s. It has been noticed that the observed delays were similar to the delays between X-ray and optical/IR bands in other black hole and neutron star sources. We discuss the possible mechanisms/processes to explain the observed delays in the dynamical CCF. This work has been done in collaboration with C. S. Choi and A. R. Rao.

ASAS J083241+2332.4: A new extreme low mass ratio overcontact binary system

We present the R- and V-band CCD photometry and Hα line studies of an overcontact binary ASAS J083241+2332.4. The light curves exhibit totality along with a trace of the O'connell effect. The photometric solution indicates that this system falls into the category of extreme low-mass ratio overcontact binaries with a mass ratio, q $\sim$ 0.06. Although a trace of the O' Connell effect is observed, constancy of the Hα line along various phases suggest that a relatively higher magnetic activity is needed for it to show a prominent fill-in effect. The study of O-C variations reveals that the period of the binary shows a secular increase at the rate of dP/dt $\sim$ 0.0765 s years^{-1}, which is super-imposed by a low, but significant, sinusoidal modulation with a period of $\sim$ 8.25 years. Assuming that the sinusoidal variation is due to the presence of a third body, orbital elements have been derived. There exist three other similar systems, SX Crv, V857

Her, and E53, which have extremely low mass ratios and we conclude that ASAS J083241+2332.4 resembles SX Crv in many respects. Theoretical studies indicate that at a critical mass ratio range, $q_{critical} = 0.07 - 0.09$, overcontact binaries should merge and form a fast rotating star, but it has been suggested that $q_{critical}$ can continue to fall up to 0.05 depending on the primary's mass and structure. Moreover, the obtained fill-out factors (50% - 70%) indicate that mass loss is considerable and hydrodynamical simulations advocate that mass loss from L_2 is mandatory for a successful merging process. Comprehensively, the results indicate that ASAS J083241+2332.4 is at a stage of merger. The pivotal role played by the subtle nature of the derived mass ratio in forming a rapidly rotating star has been discussed. This work has been done in collaboration with S. Malu, C. S. Choi and P. Vivekananda Rao.

Parijat Thakur

Investigating close-in extra-solar planets through photometric follow-up of their transits

The objective of the photometric follow-up observations is to improve the estimates of the physical and orbital parameters of the extra-solar planetary systems, as well as to refine the ephemeris for the orbital periods and mid-transit times required for the future transit observations. In addition, this allows to estimate the mid-transit times to examine the transit timing variations (TTVs) with greater accuracies, which would lead to confirm the presence or absence of the additional low-mass planets in the extra-solar planetary systems. We process the four photometric follow-up transit data of TrES-3 extra-solar planetary system observed from 1.3m telescope at Devsthal, ARIES, Nainital, as well as those of five transit data observed from 0.8m telescope at Tenagra Observatory, Arizona, US, using the standard procedures within IRAF. The differential photometry is performed to plot the TrES-3 light curve for each transit events by employing the aperture photometry task phot within IRAF. In order to have refine estimate of the ephemeris and improved determination of the above mentioned parameters, We analyze these nine transit curves as well as those available in the literatures and Exoplanet Transit Database (ETD). With the inclusion of new ephemeris and transit light curves, TTVs would be examined soon for the TrES-3 extra-solar planetary system. This work has been done in collaboration with Ing-Guey Jiang and Vineet Kumar.

Arun Thampan

Fast spinning strange stars: possible ways to constrain interacting quark matter parameters

For a set of equation of state (EoS) models involving interacting strange quark matter, characterized by an effective bag constant (B_{eff}) and a perturba- tive QCD correction term (a_4), we construct fully general relativistic equilibrium sequences of rapidly spinning strange stars for the first time. Computation of such sequences is important to study millisecond pulsars and other fast spinning compact stars. Our EoS models can support a gravitational mass (M_G) up to $\approx 3.0 M\odot$ and a spin frequency (ν) up to $\approx$ 1250 Hz, and hence, are fully con- sistent with measured MG and ν values. This work reports the effects of B_{eff} and a_4 on measurable compact star properties, which could be useful to find possible ways to constrain these fundamental quark matter parameters, within the ambit of our EoS models. We confirm that a lower Beff allows a higher mass. Besides, for known MG and ν, measurable parameters, such as stellar radius, radius-to-mass ratio and moment of inertia, increase with the decrease of B_{eff} . Our calculations also show that a_4 significantly affects the stellar rest mass and the total stellar binding energy. As a result, a_4 can have strong signatures in evolutions of both accreting and non-accreting compact stars, and the observed distribution of stellar mass and spin, orbital period and other source parame- ters. Finally, we compute the parameter values of two important pulsars, PSR J1614-2230 and PSR J1748-2446ad, which may have implications to probe their evolutionary histories, and for constraining EoS models. This work has been done in collaboration with Sudip Bhattacharyya, Ignazio Bombaci and Domenico Logoteta.

Online courses: Challenges and opportunities for education in India

Regular lecture courses fail to engage students for the reason that the courses are not "on demand". At the same time, an interactive session is important for understanding of the subject. Keeping this in mind, it becomes advantageous to have an accessible version of the course so that the students can reach out when ready. Together with the need for a fair system of evaluation in the continuous assessment, we have initiated a pilot online (hybrid) course in our department. The courses added, to begin with, are those that are computer based (Astrophysics Lab and C Programming Lab). However, with increasing sophistication, it is possible to bring some of the core courses to the online medium. Initial results show that students enjoy the medium, and furthermore, that the mechanism reduces (to some extent) the disparity in the knowledge in the class. This work has been done in collaboration with Agughasi Victor Ikechukwu.

Paniveni Udayashankar

Supergranulation: A convective phenomenon

We study the complexity of supergranular cells using the intensity patterns obtained from the Kodaikanal Solar Observatory in 1999 during the active phase of the Sun. The data consist of visually identified supergranular cells, from which a fractal dimension D for supergranulation is obtained according to the relation $P \propto A^{D/2}$, where A is the area and P is the perimeter of the supergranular cells. We find a fractal dimension close to about 1.2, which is consistent with that for isobars, and suggests a possible turbulent origin. We also study the supergranular area versus latitude relation.

Supergranular physical parameters

We study the complexity of supergranular cells using SOHO Dopplergrams and intensity patterns obtained from the Kodaikanal Solar Observatory during the 23rd solar cycle. The Data consists of visually identified supergranular cells, from which a fractal dimension D for supergranulation is obtained according to the relation $P \propto A^{D/2}$ where A is the area and P is the perimeter of the supergranular cells. We find a dependence of the fractal dimension on the area of the cell. The cell circularity shows a dependence on the perimeter with a peak around (1.1-1.2) $\times 10^5$ m. We also study the dependence of the area of supergranular cells with respect to the latitude and find that the cells are situated symmetrically about the 15° latitude.

A. A. Usmani

A dark energy model in Kaluza-Klein cosmology

We study a dynamic Λ model with varying gravitational constant G under the Kaluza-Klein cosmology. Physical features and the limitations of the present model have been explored and discussed. Solutions are found mostly in accordance with the observed features of the accelerating universe. Interestingly, signature flipping of the deceleration parameter is noticed and the present age of the Universe is also attained under certain stringent conditions. We find that the time variation of gravitational constant is not permitted without vintage Λ. This work has been done in collaboration with Utpal Mukhopadhyay, Ipsita Chakraboarty and Saibal Ray.

Analysis of p-^{4,6,8}He and p-^{6,8,9,11}Li scattering at 700 MeV

The Glauber model is used to analyze the elastic scattering of protons from He and Li isotopes at 700 MeV. The calculations require two inputs: The nucleonnucleon (NN) amplitude and the nucleon density distributions for the target nuclei. The NN amplitude is taken from the available NN scattering data, and for the target nuclei, we use some of the nucleon density distributions available in the literature. The emphasis, in this work, is to study the sensitivity of the calculated differential cross sections for p-^{4,6,8}He scattering on the density distributions used, and to compare the results with some recent findings in view of assessing the suitability of nucleon density distributions for a given nucleus at relatively low and intermediate energies. The results demonstrate that the study of p-nucleus scattering could be helpful in providing useful information about the behaviour of matter density distribution in the surface and interior regions of a nuclear medium. Further, we find that the phase of the NN amplitude plays a role in providing a better description of the experimental data in all the cases. This work has been done in collaboration with Deeksha Chauhan and Z. A. Khan.

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120. Nilkanth D. V*agshette, S.S. Sonkamble,* ***Sheo K. Pandey*** *and Madhav K. Patil, (*2015) *X-ray emission from a prominent dust lane lenticular galaxy NGC 5866* [arXiv: 1509.08728].

121. Katri Huitu**, P. N. Pandita** and Paavo Tiitola (2015) *Renormalization group invariants and sum rules in the deflected mirage mediation super-symmetry breaking*, Phys. Rev. D, **92**, 075037.

122. B. Ananthanarayan, Jayita Lahiri and **P. N. Pandita** (2015) *Invisible decays of the heavier Higgs- Boson in the minimal super-symmetric standard model*, Phys. Rev. D, **91**, 115025.

123. M. Buragohain, **Amit Pathak**, P.J. Sarre, T. Onaka and I. Sakon (2015) *Theoretical study of deuteronated PAHs as carriers for IR emission features in the ISM,* MNRAS, **454**, 193.

124. I. Sakon, K. Sato, T. Onaka, Seiji Kimura, ... and **Amit Pathak** (2015) *Infrared properties of laboratory-synthesized Nitrogen-containing Carbonaceous Composites (NCCs)*, Asian J. Phys. (Special issue on Constituents of Interstellar Medium), **24**, 1143.

125. M. Buragohain and **Amit Pathak** (2015) *Spectral properties of astrophysical polycyclic hydrocarbons*, Asian J. Phys. (Special issue on Constituents of Interstellar Medium), **24**, 1127.

126. R. Sarma, **Amit Pathak** and J.K. Sarma (2015) *FUSE view of interstellar OVT*, Asian J. Phys. (Special issue on Constituents of Interstellar Medium), **24**, 1019.

127. S.S. Sonkamble, Nilkanth D. Vagshette, P. K. Pawar and **Madhav K. Patil** (2015) *X-ray cavities and temperature jumps in the environment of the strong cool core cluster Abell 2390*, Ap. Space Sci., **359**, 61.

128. Nilkanth D. Vagshette, S.S. Sonkamble and **Madhav K. Patil** (2015) *X-ray emission from a prominent dust lane lenticular galaxy NGC 5866*, Asian J. Phys., **24,** 1031.

129. **Bikash Chandra Paul,** P. K. Chattopadhyay and S. Karmakar (2015) *Relativistic anisotropic star and its maximum mass in higher dimensions*, Ap. Space. Sci.**,** **356**, 327.

130. Pragati Pradhan, Biswajit Paul, Harsha Raichur and **Bikash Chandra Paul** (2015) *Variations of the harmonic components of the X-ray pulse profile of PSR B1509-58*, Res. Astron. Ap., **15**, 28.

131. Pragati Pradhan, Biswajit Paul, **Bikash Chandra Paul,** Enrico Bozzo and Tomaso M. Belloni (2015*) Is 4U 0114+65 an eclipsing HMX ?*, MNRAS (Accepted) [Doi:10.1093/mnras/stv2276].

132. P. K. Chattopadhyay and **Bikash Chandra Paul** (2016) *Density dependent B parameter of relativistic stars with anisotropy in pseudo-spheroidal spacetime*, Ap. Space Sci., **361**, 145.

133. S. Das, R. Sharma, **Bikash Chandra Paul** and R. Deb (2016) *Dissipative gravitational collapse of an (an)isotropic star,* Ap. Space Sci., **361**, 1.

134. P. S. Debnath and **Bikash Chandra Paul** (2016) *Viscous cosmologies with modified Chaplygin gas*, Intl. J. App. Phys., **3**, issue 2.

135. Savithri H. Ezhikode, Gulab C. Dewangan, Ranjeev Misra, ..., **Ninan Sajeeth Philip** and Ajit Kembhavi (2016) *UV and X-Ray variability of the narrow-line Seyfert 1 galaxy Ark 564,* Res. Astron. Ap. (Accepted).

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141. R. K. Mishra, A. Chand and **Anirudh Pradhan** (2016) *Dark energy models in f(R, T) theory with variable deceleration parameter*, Intl. J. Th. Phys., **55**, 1241.

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143. Alireza Sepehri, **Anirudh Pradhan** and Somayyeh Shoorvazi (2016) *F(R) bouncing cosmology with future singularity in brane-anti-brane system,* Ap. Space Sci., **361**, 58.

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173. Chow Choong Ngeow, Shashi M. Kanbur, Anupam Bhardwaj and **Harinder P**al **Singh** (2015*) Period-luminosity relations derived from OGLE-III fundamental mode Cepheids II: The small Magellanic Cloud Cepheids*, Ap. J., **808**, 67.

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175. K. Sharma, P. Prugniel and **Harinder Pal Singh** (2016) *New atmospheric parameters and spectral interpolator for the MILES cool stars*, Astron. Ap., **585**, A64.

176. Anupam Bhardwaj, Shashi M. Kanbur, L. M. Macri, **Harinder Pal Singh,** Chow Choong Ngeow, et al. (2016) *Large Magellanic Cloud near-infrared synoptic survey - II: The Wesenheit relations and their application to the distance scale*, Astron. J., **151**, 88.

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181. Agughasi Victor Ikechukwu and **Arun Varma Thampan** (2016) *Massive open online courses: Challenges and opportunities for education in India*, IJRSD, **3**, 2321.

182. Suhel Ahmad, Deeksha Chauhan, Z.A. Khan and **Anisul Ain Usmani (2015)** *Neon-^{12}C reaction cross section at 240 MeV/nucleon*, **Nucl. Phys., 60, 454.**

183. Asloob Ahmad Rather, Minita Singh, Z.A. Khan and **Anisul Ain Usmani (2015)** ^{16,20,21,23}O-^{12}C reaction cross sections at 1GeV/nucleon, **Nucl. Phys., 60, 452.**

(B) PROCEEDINGS

1. **Surajit Chattopadhyay** (2015) *Holographic reconstruction of scalar field models of dark energy in the background of Brans-Dicke cosmology*, Euro. Phys. Soc. Conf. on High Ener. Phys., Vienna, Austria, 22.

2. **Surajit Chattopadhyay** and Sudipto Roy (2015) *Dependence of Brans-Dicke parameter on scalar field,* Springer Procds. in Maths. Stat., **146**, 177, and Conf. on Emerging Trends in Applied Mathematics, University of Calcutta [ISBN: 978-81-322-2547-8].

3. **Surajit Chattopadhyay** and Antonio Pasqua (2016) *Consequences of holographic scalar field dark energy models in Chamelon Brans-Dicke cosmology*, Springer Procds. Phys., **174**, 487, and XXI DAE-BRNS High Ener. Phys. Symp., IIT Guwahati [ISBN: 978-3-319-25617-7].

4. **S. Dev**, Lal Singh and Desh Raj (2016) *Phenomenological analysis of two texture zeros/vanishing co-factors of neutrino mass matrices,* Springer Procds. Phys., **174**, 279.

5. **Broja G. Dutta**, P. S. Pal and S. K. Chakrabarti (2015) *Lag variability of GRS 1915+105 during plateau* states, *Recent Trends in the Study of Compact Objects, Th. Obs., ASI Conf. Series, **12**, 121.*

6. **Broja G. Dutta** and S. K. Chakrabarti (2016) *Inclination effects and time variability properties of black hole transients*, Procds. 14th Marcel Grossmann Meeting on General Relativity, edited by Massimo Bianchi, Robert T. Jantzen and Remo Ruffini, *World Scientific, Singapore (Accepted).*

7. ***Sheo K. Pandey**, Sheetal K. Sahu, Laxmikant Chaware and Mahadev Baburao Pandge (2015) Multi-phase ISM in early type galaxies: A case study of NGC 708*, Oral presentation at IAU XXIX General Assembly, held at Honolulu, Hawaii, during August 3 - 14, 2015.

8. *Sheetal K. Sahu, **Sheo K. Pandey**, N.K. Chakradhari and Mahadev Baburao Pandge (2015) Multi-colour surface photometry of a sample of low luminosity radio galaxies*, Poster presented at IAU XXIX General Assembly, held at Honolulu, Hawaii, during August 3 - 14, 2015.

9. Sheetal K. Sahu, **Shoe K. Pandey**, Laximikant Chaware and M.B. Pandge (2016) *Multi-phase ISM in low luminosity radio galaxies: A case study of NGC 708*, Procds. IAU Symp., No. 315, 2015 [arXiv: 160308377], Eds: P. Jablonkaeds, F. van der Tak and P. Andre

10. **Surajit Paul,** Prateek Gupta, Reju Sam John and Venkat Punjabi (2016) *Uniqueness of galaxy groups in the structural hierarchy from its radio signature*, Conf. on the Many Facets of Extragalactic Radio Surveys, Bologna, Italy, Procds. Sci., **267**, 65.

11. Aruna Govada, Bhavul Gauri and **Sanjay Kumar Sahay** (2015) *Distributed multi-class SVM for large data sets,* ACM Digital Library, Procds. 3rd Intl. Symp. Women Comp. Info., 54.

12. Aruna Govada, Bhavul Gauri and **Sanjay Kumar Sahay** (2015) *Centroid based binary tree structured SVM for multi-classification*, IEEE Xplore [DOI: 10.1109/ICACCI.2015.7275618], Procds. 4th Intl. Conf. Adv. Comp. Comm. Info.

13. Aruna Govada, Pravin Joshi, Sahil Mittal and **Sanjay Kumar Sahay** (2015) *Hybrid approach for inductive semi-supervised learning using label propagation and support vector machine*, Springer, LNAI, Machine Learning and Data Mining in Pattern Recognition, Procds. 11th Intl. Conf. MLDM, Germany, **9166**, 199.

14. **Sanjay Kumar Sahay** and Ashu Sharma (2016) *Grouping the executables to detect malware with high accuracy*, Elsevier, Procedia Comp. Sci.,**78**, 667.

15. R.K. Roul and **Sanjay Kumar Sahay** (2016) *K-means and wordnet based feature selection combine with extreme learning machines for text classification*, Springer, LNCS, 12th Procds. Distributed Comp. and Internet Tech., **9581**, 103.

16. **Sanjay Baburao Sarwe** (2015) *Linear isentropic equation of state in formation of black hole and naked singularity*, Procds. Intl. Conf. on Phys. Interpretations of Rel. Th., 454.

17. Y. Wu, P. Prugniel, A. Luo and **Harinder Pal Singh** (2015) *Comparison of the stellar atmospheric parameter determining accuracy of the SSPP and the full spectrum fitting depending on S/N,* Procds. IAU General Assembly, Meeting 29, id. 2254764.

18. Shashi M. Kanbur, Anupam Bhardwaj, **Harinder Pal Singh** and Chow Choong Ngeow (2015) *Period-colour and amplitude-colour relations for RR Lyraes,* Procds. Conf. High Precision Studies of RR Lyrae Stars [arXiv: 1512.03494].

(C) BOOKS

1. **Suresh Chandra**, Mohit K. Sharma and Monika Sharma (2015) *Text Book of Engineering Physics,* Vol. II, NAROSA Publishing House Pvt. Ltd., New Delhi (2015) [ISBN: 978-81-8487-451-8], and Alpha Science International Ltd., Oxford (UK) [ISBN: 978-1-84265-968-7].

2. **Rupjyoti Gogoi** *(2015) Application of Self-similarity in Deep Inelastic Scattering, Science Spectrum (One Chapter).*

3. R. Kumar and **Nagendra Kumar** (2016) *Differential Equations and Integral Transforms*, CBS Publishers, Delhi**.**

4. Pragati Pradhan, Biswajit Paul, Harsha Raichur and **Bikash Chandra Paul** (2015) *Variability of pulse profile of a rotation powered pulsar PSR B1509-58*, Non-linear Dynamics and its Application, Published by Book Centre, page 240 [ISBN:978-81-921612-6-6].

5. **Bikash Chandra Paul** (2015) *An introduction to astronomical data analysis* (Edited), Scholars' Press [ISBN 978-3-639-85990-4].

6. **Bikash Chandra Paul** and S. Ghosh (2015) *Estimation of observational constraints of the parameters in emergent universe model*, An Introduction to Astronomical Data Analysis (Edited), Ch. 5, 96.

7. **Bikash Chandra Paul** and P. Thakur (2015) *Observational Constraints on Chaplygin gas: A Review, An Introduction to Astronomical Data Analysis* (Edited), Chapter 7, 149.

(D) SUPERVISION OF PH.D. THESIS

1. **Ujjal Debnath** (2015) *Title:* Study of thermodynamical properties of the Universe.
Student: Samarpita Bhattacharya

2. **Ujjal Debnath** (2015) *Title:* Study of some cosmological models in the accelerating Universe.
Student: Piyali Bagchi Khatua

3. **Sushant G. Ghosh** (2015) Title: Black holes in modified theories of gravity and their properties, Jamia Millia Islamia, New Delhi.
Student: Uma Papnoi

4. **Sushant G. Ghosh** (2015) Title: Penrose process and particle acceleration in modified theories of gravity, Jamia Millia Islamia, New Delhi.
Student: Pankaj Sheoran

5. **Naseer Iqbal** (2015) Title: Role of peculiar velocities of galaxies in gravitational clustering of cosmological many body problem, University of Kashmir, Srinagar.
Student: Tabasum Masood.

6. **V.C. Kuriakose** (2015) Title: Studies on some aspects of black hole thermodynamics, Cochin University of Science and Technology, Kochi.
Student: R. Tharanath

7. **V.C. Kuriakose** (2015) Title: Studies on scattering and thermodynamics of black holes in F(R) theory and Einstein theory, Cochin University of Science and Technology, Kochi.
Student: Sneesha Sebastian

8. **Anirudh Pradhan** (2016) Title: Study of dynamic and physical behaviours of the Universe in the light of cosmological constant, Sam Higginbotom Institute of Agriculture and Sciences (Deemed University), Allahabad.
Student: Rekha Jaiswal

9. **T.R. Seshadri** (2015) Title: Cosmological magnetogenesis, University of Delhi.
Student: Kumar Atmjeet

(E) AWARDS AND DISTINCTIONS

Asis Kumar Chattopadhyay and **Tanuka Chattopadhyay**

Statistical Methods for Astronomical, Data Analysis, Springer Award: Outstanding Publication in Astrostatistics (2016) by International Astrostatistics Association (IAA)

Asis Kumar Chattopadhyay

Fellow of International Astrostatistics Association, 2016.

Surajit Chattopadhay

SERB/DST, Government of India, for Centre for International Cooperation in Science (CICS) Travel Fellowship and European Physical Society (EPS) individual member travel grant to participate in the European Nuclear Physics Conference (EuNPC 2015) in Groningen, the Netherlands, during August 31 to September 4, 2015.

Himadri Sekhar Das

Inspired Teachers' in-Residence Programme at Rashtrapati Bhavan (2015): Honoured by Hon'ble President of India, **Shri Pranab Mukherjee, held during June 6** to **June 12, 2015**. This is the highest civilian recognition for university-level teachers.

Paragon Excellence Award (2015): Honoured by *Paragon*, an NGO in Badarpur (Assam), for the service rendered in the field of education and nation building.

Badam Singh Kushvah

Canara Bank Research Publication Award (2015).

Biswajit Pandey

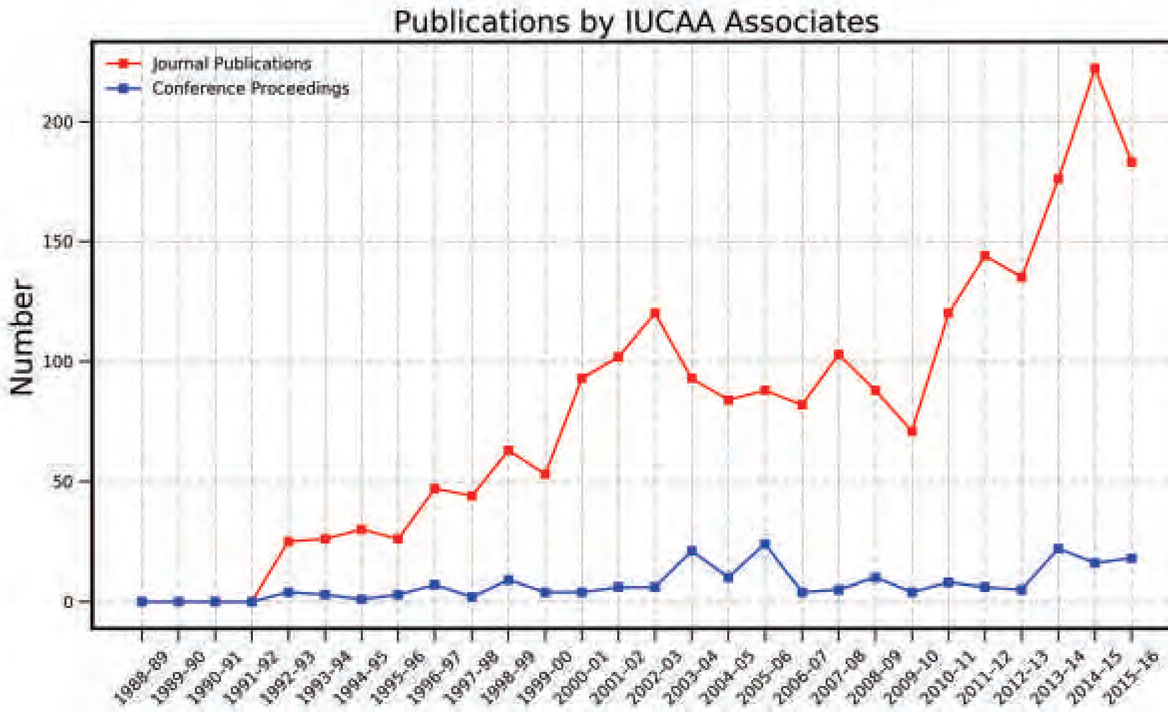
DST Extra Mural Research (EMR) grant for three years for the project: *Galaxy formation and evolution in the filamentary cosmic web: Exploration and analysis of the Sloan Digital Sky Survey Data Release Twelve.*

Surajit Paul

SFB Fellowship, DESY (Hamburg, Germany) for visiting Hamburg University as Guest Professor, for collaboration during 2015 - 2016.

Parijat Thakur

Project title: *Investigating close-in extra-solar planets through photometric follow-up of their transit*, has been awarded grant by the University Grants Commission, New Delhi.



DEPARTMENT OF PHYSICS AND ASTROPHYSICS, UNIVERSITY OF **DELHI**

Coordinator: T.R. Seshadri

Research Areas

Magnetogenesis in early universe, Magnetic fields in galactic systems and inter-galactic region, Cosmic reionization and 21 cm cosmology, and High energy physics in higher dimensional cosmology.

Research

- The origin of seed magnetic field over large scale using higher dimensional cosmology.
- Clustering properties of H1 clouds.

  (Brief report of these could be found in this Annual Report under "Research by Visiting Associates" by T.R. Seshadri.)

- Study of magnetic fields in astrophysics is an important area, in which IRC Delhi is engaged, especially, in the context of the SKA. This work involves rotation measure with systems both with and without MgII lines.
- While Hydrogen reionization in cosmology is fairly well studied, relatively less focus has been on Helium reionization. At IRC Delhi, research in annihilating dark matter as a source of Helium reionization is being pursued. In particular, the role of Somerfield enhancement is being studied.
- In addition, research is also being pursued in the area of application of high energy physics in cosmology, especially in the context of higher dimensional theories.

Publications

- Nisha Rani, Deepak Jain, Shobhit Mahajan, Amitabha Mukherjee and Nilza Pires (2015) Transition Redshift: New constraints from parametric and nonparametric methods, J. Cos. Astroparti. Phys., 12, 045.
- L. Sriramkumar, Kumar Atmjeet and Rajeev Kumar Jain (2015) Generation of scale invariant magnetic fields in bouncing universes, J. Cos. Astroparti. Phys., 09, 010.
- Kumar Atmjeet, T. R. Seshadri and Kandaswamy Subramanian (2015) Helical cosmological magnetic fields from extra-dimensions, Phys. Rev. D, 91, 103006.
- Bidisha Bandyopadhyay and Dominik R.G. Schleicher (2015) Helium reionization in the presence of self-annihilating clumpy dark matter, Phys. Rev. D, 92, 023508.
- Akshay Rana, Deepak Jain, Shobhit Mahajan and Amitabha Mukherjee (2016) Revisiting the distance duality relation using a non-parametric regression method (Accepted in J. Cos. Astroparti. Phys.) [astro-ph: 1512.01118].
- Mathew Thomas Arun, Debajyoti Choudhury (2016) Bulk gauge and matter fields in nested warping: II. Symmetry breaking and phenomenological consequences [astro-ph: 1601.02321].

Ph.D. Thesis

Title: Cosmological magnetogenesis, Student: Kumar Atmjeet, Supervisor: T. R. Seshadri (Degree awarded by the University of Delhi).

Number of Ph.D. students making active use of IRC facilities: 10

Number of post-doctoral fellow using IRC facilities: 1

Seminars

- Smita Mathur (Ohio State University, USA), on Missing baryons and missing metals in galaxies: Clues from our Milky Way, July 23, 2015.
- Irshad Momammad (Physik-Institut and Institute for Computational Science, Zurich, Swizerland) on Probing the distribution of matter in the Universe using gravitational lensing, September 24, 2015
- Dawood Kothawala (Indian Institute of Technology Madras, Chennai) on Small scale structure of spacetime, February 5, 2016.

At the IRC, Delhi, weakly journal club talks and lectures are held by people in IRC. In addition, active discussion of research work by the users of IRC is an active regular feature. The existence of IRC has helped in building a unique research atmosphere in the University. The facilities are extensively used by M.Sc. students. Thus, IRC contributes, not only towards research, but also towards teaching.

Lectures given using IRC Facility

- Structures in the Universe, in the Refresher Course, at Jawaharlal Nehru University, New Delhi.
- Understanding the Universe through the Cosmic Microwave Background Radiation, at the Indian Institute of Technology Madras, Chennai.
- Ancient light, at Uluberia College, Howrah, West Bengal.
- Probing the Universe through the Cosmic Microwave Background Radiation, at ARIES, Nainital.
- Probing the Universe through the Cosmic Microwave Background Radiation, at Ashutosh College, Kolkata (via Skype).

DEPARTMENT OF PHYSICS, COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY, **KOCHI**

Coordinator: V. C. Kuriakose

Data Centre

The Data Centre is being now used by M.Sc. students for their project works, and research students for their research studies. Undergraduate and post-graduate students from neighbouring colleges and institutes carried out their summer projects using these facilities.

Research Areas

Physics of black holes, Extended theories of gravity, and Bose-Einstein condensation. Four research students are now doing their research studies in these areas.

Workshops and Schools

1. Workshop on Time Domain Astronomy and Cosmology

St. Thomas College, Kozhencherry, in association with IUCAA Resource Centre (IRC), CUSAT, Kochi and C. M. S. College, Kottayam, conducted a workshop on Time Domain Astronomy and Cosmology, during July 9 - 11, 2015. (Detailed report of this workshop could be found in IUCAA Quarterly Bulletin, KHAGOL, No. 104, October 2015, page 3.)

2. School on Gravitation and Cosmology

IRC, CUSAT, Kochi, organized a School on Gravitation and Cosmology, during August 24 - 26, 2015. (Detailed report of this school could be found in IUCAA Quarterly Bulletin, KHAGOL, No. 104, October 2015, page 6.)

3. Workshop on Multi-wavelength Astronomy

St. Thomas College, Kozhencherry, in association with IUCAA Resource Centre (IRC), CUSAT, Kochi and C. M. S. College, Kottayam, conducted a workshop on Time Domain Astronomy and Cosmology, during July 9 - 11, 2015. (Detailed report of this workshop could be found in IUCAA Quarterly Bulletin, KHAGOL, No. 104, October 2015, page 3.)

4. School on Gravitation and Cosmology

The Department of Physics, Providence Women's College, Kozhikode, in collaboration with IRC, Kochi and IUCAA, organized an introductory level Workshop on Multi-wavelength Astronomy for the teachers and post-graduate students of the college, and also of the neighbouring colleges, during November 25 - 27, 2015. The main aim of the workshop was to make the participants aware of the theoretical and observational aspects of Multi-wavelength Astronomy, and the present challenges in this field. The programme consisted of lectures and hands-on sessions. The programme started with an inauguration session, chaired by Sr. Neetha (Principal of the College). This was followed by a public lecture by Ranjeev Misra (IUCAA) on AstroSat, India's first multi-wavelength space observatory, recently launched by ISRO. He explained the major payloads, and its main scientific objectives. The technical talks were given by V. C. Kuriakose (CUSAT) on An introduction to multi-wavelength astrophysics, C.S. Stalin (IIA, Bengaluru) on The multi-wavelength view of the most powerful X-ray sources, Active Galactic Nuclei, Subramania Athirey (Manipal Centre for Natural Sciences) on X-ray instrumentation, Ranjeev Misra on Radiative processes in astrophysics, C.D. Ravikumar (Calicut University, Kozhikode) on Evolution of galaxies, Anand Narayanan (IIST, Thiruvananthapuram) on Studying the universe by splitting light, Ninan Sajeeth Philip (St.Thomas College, Kozhencherry) on Sloan Digital Sky Survey, and K. G. Biju (W.M.O. College, Wayanad) on An introduction to radio astronomy. The afternoon sessions were devoted for hands-on sessions, and these sessions were handled by Ranjeev Misra, Subramania Athirey and C. D. Ravikumar. Jeena K. and Sini R. of the Department of Physics of the College were the local organizers.

4. National School on Gravitational Waves

IRC, CUSAT, Kochi, in association with the Department of Physics, M. A. College of Arts and Science, Kothamangalam, organised a National School on Gravitational Waves, during December 28, 2015 – January 1, 2016 at M. A. College of Engineering, Kothamangalam. (Detailed report of this school could be found in IUCAA Quarterly Bulletin, KHAGOL, No. 106, April 2016, page 12.)

Publications

- Structures in the Universe, in the Refresher Course, at Jawaharlal Nehru University, New Delhi.
- Understanding the Universe through the Cosmic Microwave Background Radiation, at the Indian Institute of Technology Madras, Chennai.
- Ancient light, at Uluberia College, Howrah, West Bengal.
- Probing the Universe through the Cosmic Microwave Background Radiation, at ARIES, Nainital.
- Probing the Universe through the Cosmic Microwave Background Radiation, at Ashutosh College, Kolkata (via Skype).

Seminars/Colloquia

- Ajit Kembhavi (IUCAA) on The next biggest challenges in Physics: Gravitational wave detection, and S. K. Pandey (Pt. R. S. University, Raipur) on Astronomy using small telescopes, July 8, 2015.
- J.M. Shivakumar (University of Hyderabad) on Higher spin theories: Past, present and future, July 23, 2015.
- B. R. Iyer (ICTS, Bengaluru) (two seminars) on General relativity: Beyond insight and elegance to observations and astronomy, and LIGO-India: Beyond gravitational wave detection to gravitational wave astronomy, February 1, 2016.
- Jayant V. Narlikar (IUCAA) on Are we alone?, February 11, 2016.

Lectures given by the Coordinator at other places

- Einstein and beyond, at the Department of Physics, University of Kerala, July 30, 2015.
- 100 years of general relativity, at the Government College, Chittur, October 24, 2015.
- Optical solitons with PT symmetry, at the Farook College, Kozhikode (in the National Conference on Modern Optics and Material Science), December 17, 2015.
- Optical solitons with PT symmetry, at K.S.R. College of Engineering, Tirunchengode (in the National Conference on Advances in Material Science and Non-linear Systems), January 8, 2016.
- Series of lectures on general relativity, at the Department of Astrophysics, Central University of Pondicherry, during February 22 - 24, 2016.

Public Outreach Programmes

Department of Physics, CUSAT, organized a workshop for school students, during April 6 - 10, 2015 in collaboration with IRC, Kochi. These students were given training in assembling small telescopes. There were lectures on astronomy and astrophysics and related topics. In addition, there were lectures on other topics in physics and the students were given training on doing experiments in physics, and they visited the different research laboratories in the department. There were 40 participants from different schools in Kerala.

IRC, Kochi, organised an outreach programme to school students of class 8 at three different places in Kerala. This programme was led by Jayant V. Narlikar and Mangala Narlikar. The talks were by J. V. Narlikar on Are we alone?, and Mangala Narlikar on Mathematics through puzzles, and each talk was followed by an interactive session with school students. The programmes were held at C. M. S. College, Kottayam (February 8, 2016), Nirmala College, Muvattupuzha (February 9, 2016) and Rajagiri Public School (February 10, 2016). About 80 students each selected from different schools attended these programmes. From the feedback obtained from the students, it was understood that they enjoyed the programme and the whole programme (talks and interactive sessions) was very enlightening to them.

The research scholars, Jishnu Suresh, Lini Deavssy and Prasia P. rendered valuable services in making the public outreach programmes and other IRC activities a great success.

DEPARTMENT OF STATISTICS, UNIVERSITY OF CALCUTTA, **KOLKATA**

Coordinator: Asis Kumar Chattopadhyay
Joint Coordinator: Narayan Banerjee

Research Areas

Galaxy and star formation theory, Large scale simulation studies, Mathematical and statistical software as well as development of computer programmes and statistical techniques for the analysis of astronomical data, and Theory of relativity and cosmology.

Project works carried out by the post-graduate students

1. Supervised by Asis Kumar Chattopadhyay, Department of Statistics, University of Calcutta

- Search for the origin of gamma ray bursts through clustering, including spatial effect, by Souradeep Chattopadhyay, Department of Statistics, University of Calcutta.
- Detection of proper regression line under unknown cause and effect relationship, by Rahul Chowdhury, Department of Statistics, Indian Institute of Technology, Kanpur.

2. Supervised by Tanuka Chattopadhyay, Department of Applied Mathematics, University of Calcutta

- Modelling the existence of dark matter in a typical spiral galaxy, by Nibedita Maity.
- Estimation of the mass of the local group using different methods and computation of the mass to light ratio, by Ekata Sen.
- Fundamental plane for elliptical galaxies and globular clusters, by Shibani Sardar
- Orbit of star under different galaxy potential, by Debasish Mondal.
- H - R diagram of stars for a real data set of stellar parameters, by Joydeep Tahasilder.
- The evolution of stellar population in a giant galaxy, by Sumanta Halder.

(All these students were from the Department of Applied Mathematics, University of Calcutta)

Meeting

Regional Meeting on Trends and Challenges in Astronomy and Astrophysics

The Department of Applied Mathematics, University of Calcutta, and IRC, Kolkata, jointly organized a Regional Meeting on Trends and Challenges in Astronomy and Astrophysics, during September 10 - 12, 2015. (Detailed report of this meeting could be found in IUCAA Quarterly Bulletin, KHAGOL, No. 104, October 2015, page 5.)

Publications

IRC facilities have been used for the following publications:

- Suma Debsarma, Tanuka Chattopadhyay, Sukanta Das and Daniel Pfenniger (2016) Episodic model for star formation history and chemical abundances in giant and dwarf galaxies, MNRAS (in Press).
- Tanuka Chattopadhyay, Abisa Sinha, Asis Kumar Chattopadhyay (2016) Influence of binary fraction on the fragmentation of young massive clusters: A Monte Carlo simulation, Ap. Space Sci., 361, 120.
- Krishnendra S. Ganguly, Soumita Modak, Krishna S. Ganguly and Asis Kumar Chattopadhyay (2016) Study on temporal effects on urban malaria incidences, Intl. J. Stat. Med. Res., 5, 120.
- Kalyan Das, Surupa Roy and Asis Kumar Chattopadhyay (2016) Analysis of partial ordinal longitudinal data, J. Stat. Res., 48-50(1), 15.
- Tuli De, Didier Fraix Burnet and Asis Kumar Chattopadhyay (2016) Clustering large number of extragalactic spectra of galaxies and quasars through canopies, Comm. Stat. Th. Methods, 45(9), 2638.

Seminar

Marco Banterle (University of Paris) on Introduction to approximate Bayesian computation methods, May 18, 2015.

Lectures given by the Coordinator at other places

- 60th ISI World Statistics Congress, Special session on Astrostatistics, at Rio de Janeiro, Brazil, July 26 - 31, 2015.
- Ph.D. Course work for research scholars, at the Department of Chemical Technology, University of Calcutta, September 22 - October 7, 2015.
- Workshop on Fundamentals of Biomedical Research Methods, at the Regional Occupational Health Centre (Eastern), Salt Lake City, Kolkata, October 7 - 9, 2015.
- 2nd Biennial Conference of the Jharkhand Society of Mathematical Sciences, Mahalanobis Memorial Lecture, on Multivariate Analysis, November 21 - 23, 2015.
- Workshop on Statistical Techniques used in Research, at the Department of Statistics, Burdwan University, February 16 -19, 2016.
- Faculty Development Programme for Professionals and Academicians on Business and Financial Market Analysis, at the Institute of Cost Accountants of India (ICAI), February 22 - 28, 2016.

SCHOOL OF STUDIES IN PHYSICS AND ASTROPHYSICS, PT. RAVISHANKAR SHUKLA UNIVERSITY, **RAIPUR**

Coordinators: Sheo K. Pandey & R. C. Agrawal

Research Highlights

IRC facilities have been used by faculty members and research students for their research activities.

- Multi-wavelength study of a sample of radio loud elliptical galaxies
- Study of accretion process and jets in X-ray binaries

(Detailed report of these could be found in this Annual Report under "Research by Visiting Associates" by Sheo K. Pandey.)

- Amit Tamrakar has been carrying out his doctoral work under the supervision of Sheo K. Pandey, on Multi-wavelength isophotal shape analysis of early type galaxies. The main objective is to make use of multi-band isophotal shape analysis and ellipse fitting procedure to examine the correlation, if any, between the presence of dust as well as other phases of ISM and the higher order Fourier coefficients for a well defined sample of early-type galaxies. The work may provide new clues as regard to the role of dust, and ISM in the formation processes of early-type galaxies.

- Mahendra Verma has been registered for his Ph.D. degree, for which the thesis is entitled: A study of central regions of lenticular galaxies, under the joint supervision of Sheo K. Pandey and Sudhanshu Barwey (South African Observatory, Cape Town). The work is aimed to carry out detailed analysis of central (nuclear) regions of S0 galaxies observed with Hubble Space Telescope (HST). Volume limited sample of lenticular galaxies has been selected from the RC3 catalogue, depending on different selection parameters. RC3 catalogue contains nearly 3,476 S0 galaxies. Currently, the work on HST WFC2 archival data to examine the presence of dust and other faint features in the central regions of galaxies is in progress.

- N.K. Chakradhari has submitted a summary of his Ph.D. degree thesis entitled: Observational studies of type Ia supernovae, under the supervision of D.K. Sahu, (IIA, Bengaluru) and Sheo K. Pandey. The work was carried out in collaboration with supernovae group of IIA, headed by G.C. Anupama. Detailed photometric and spectroscopic studies of type Ia supernovae, SN 2004ab, SN 2005el, SN 2005ke, SN 2009ig, SN 2010kg, SN 2012cg and SN 2012dn, have been carried out. Out of these, SN 2004ab, SN 2005el, SN 2009ig, SN 2010kg and SN 2012cg belong to normal category. SN 2012dn and SN 2005ke are luminous and under-luminous events, respectively. The thesis presents detailed studies of SNe Ia belonging to different sub-classes, and hence can be treated as a representative sample of SNe Ia. Optical imaging and spectroscopic data on all the SNe Ia studied in this work were acquired using the 2 m Himalayan Chandra Telescope (HCT). The archived UV-optical photometric data observed with Ultra Violet Optical Telescope (UVOT) on board the Swift satellite were also used.

- Also, N.K. Chakradhari, in collaboration with Santosh Joshi (ARIES, Nainital), has been involved in the Nainital-Cape Survey, a dedicated ongoing survey programme to search and study pulsational variability in chemically peculiar (CP) stars. Multi-periodic pulsations in CP stars are important for astro-seismic studies to understand their internal structure and evolution. This survey programme is one of the longest ground-based surveys to study CP stars. The results of the survey have been presented in a series of papers, and the fourth one in this series (Joshi et. al. 2016) is recently accepted for publication in A & A. For better understanding of CP stars, they have initiated low and high resolution spectral modelling.

- As a part of MoU between School of Studies in Physics and Astrophysics, Pt. R.S. University, Raipur and ARIES, Nainital, students of M.Sc. final year, namely, Pokhraj Sahu, Virendra Dhruw, Jainendra Thakur, Kiran Sahu, Santoshi Sahu, Tanuja Gupta, Khemlata Sahu and Amitesh, visited ARIES, and completed their project work during the period.

Publications/Posters

IRC facilities have been used for the following publications:

- Nilkanth D. Vagshette, S.S. Sonkamble, Sheo K. Pandey and Madhav K. Patil, (2015) X-ray emission from a prominent dust lane lenticular galaxy NGC 5866 [arXiv: 150908728].

- Sheetal K. Sahu, Sheo K. Pandey, N.K. Chakradhari and Mahadev Baburao Pandge (2015) Multi-colour surface photometry of a sample of low luminosity radio galaxies, Poster presented at IAU XXIX General Assembly, held at Honolulu, Hawaii, during August 3 - 14, 2015.

- Sheo K. Pandey, Sheetal K. Sahu, Laxmikant Chaware and Mahadev Baburao Pandge (2015) Multi-phase ISM in early type galaxies: A case study of NGC 708, Oral presentation at IAU XXIX General Assembly, held at Honolulu, Hawaii, during August 3 - 14, 2015.

- Sheetal K. Sahu, Shoe K. Pandey, Laximikant Chaware and M.B. Pandge (2016) Multi-phase ISM in low luminosity radio galaxies: A case study of NGC 708, Procds. IAU Symp., No. 315, 2015 [arXiv: 160308377], Eds: P. Jablonkaeds, F. van der Tak and P. Andre

- S. Joshi, P. Martinez, S. Chowdhury, N.K. Chakradhari, Y.C. Joshi et al. (2016) The Nainital-Cape Survey - IV: Some new results, Astron. Ap (Accepted) [arXiv: 160303517].

- L.A. Balona, C. Engelbrecht, Y.C. Joshi, S. Josh, ..., N.K. Chakradhari et al. (2016) The hot gamma Doradus and Maia stars, MNRAS (Accepted).

- D. K. Sahu, G. C. Anupama, S. Srivastav and N. K. Chakradhari (2016) Classification of AT 2016c in NGC 5247 as a type II supernova, ATEL, 8514.

Public Outreach Programmes

Various astronomical activities have carried out during the INSPIRE summer and winter camps. Planetarium shows, sky watching programmes and telescope demonstrations were organized at various places for school/college students, teachers and public. This also includes, Lunar eclipse on April 4, 2015, and Sky watching programme on April 17, 2015 for the members of Rotary Club, Raipur.

Lectures by Sheo K. Pandey

Technical

- Variable stars using small optical telescopes, at the workshop on Time Domain Astronomy, C.M.S. College, Kottayam, July 9 - 11, 2015.

- Multi-wavelength study of complex ISM in early type galaxies, in the regional meeting on Trends and Challenges in Astronomy and Astrophysics, held at IRC, University of Calcutta, Kolkata, September 10 - 12, 2015.

- Teaching and research in observational astronomy using small telescopes, in the workshop on Astronomy with Small Telescopes, held at S.R.T.M. University, Nanded, December 8 -10, 2015.

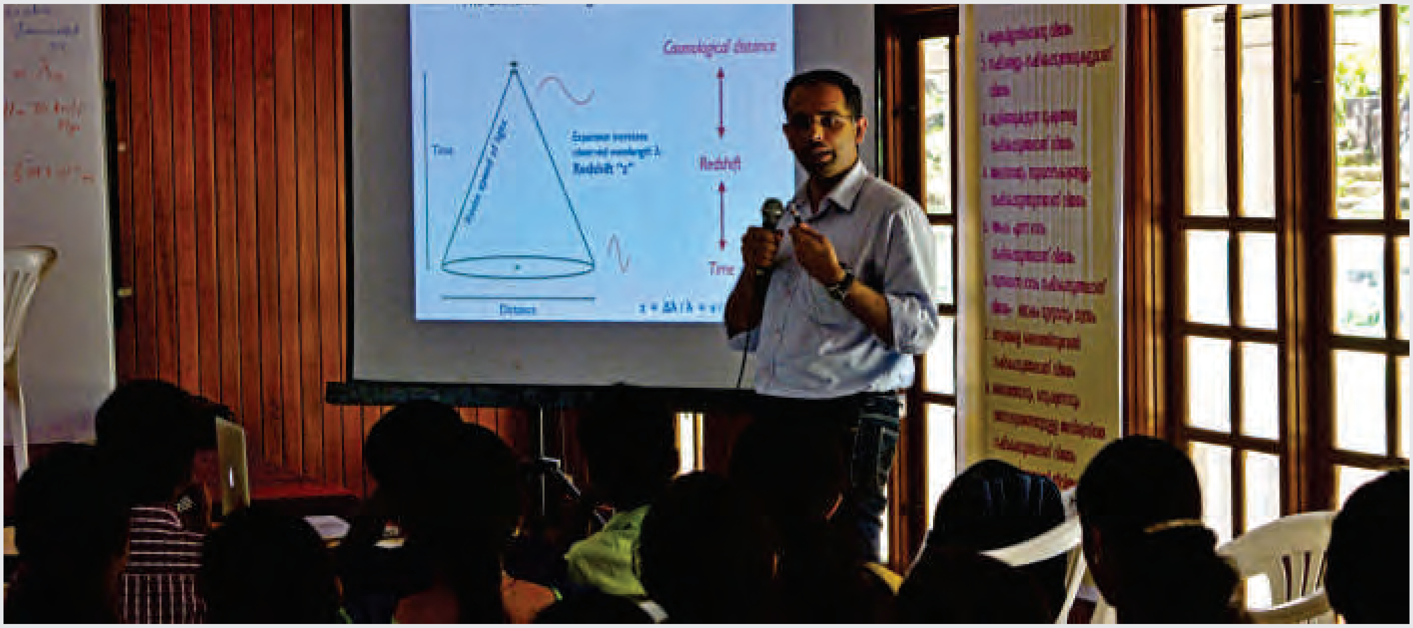
- ISM in early type galaxies, at the Visitors Programme, organised by the Department of Physics and Astrophysics, University of Delhi, March 30 - 31, 2016.

Popular

- Cosmic lights: Revealing the secrets of the Universe, at Vigyan Sabha, Korba, June 13, 2015.
- Astronomy using small optical telescopes, at CUSAT, Kochi, July 8, 2015.
- Our place in the Universe: A cosmic connection, at Atal Bhihari Hindi VishwaVidyalaya, Bhopal, August 25, 2015.
- A glimpse of our Universe, at Century Cement School, Baikunth, August 28, 2015.
- The fascinating Universe, at the School of Natural Product Studies, Jadavpur University, Kolkata, September 11, 2015.
- Stars and their evolution, at Tilak Nagar Gudhiyari, October 9, 2015.
- A brief story of our Universe, at the INSPIRE camp held at Pt. R.S. University, Raipur, December 24, 2015.
- Remarkable discoveries in Astronomy, in the workshop held at G. M. University, Sambalpur, February 27, 2016.

Lectures by N.K. Chakradhari

- Study of stars using telescopes, as a part of celebration of International Astronomy Day, at Chhattisgarh Science Centre, Raipur, April 25, 2015.
- Importance of mathematics in astronomy and astrophysics, as a part of celebration of National Mathematics Day, at S.P.C. College, Nawapara, Rajim, Raipur, January 15, 2016.



DEPARTMENT OF PHYSICS, NORTH BENGAL UNIVERSITY, **SILIGURI**

Coordinator: Bikash Chandra Paul

Research Areas

Cosmology, Compact objects, Data analysis of X-ray sources and pulsars, and Non-linear dynamics.

Data Centre

M. Sc. students and Ph.D. research scholars have been using the computers for their project work and research respectively.

Workshop and Meetings

To Celebrate the Centenary Year of Einstein's General Theory of Relativity, various programmes were arranged as follows:

1. Public Lectures

Public lecture by Jayant V. Narlikar (Emeritus Professor, IUCAA), was one of the first such programmes. Hon'ble Vice-Chancellor, Somnath Ghose inaugurated the programme on August 19, 2015. The title of the public lecture was: Searches for life in our Universe. About 250 students from different schools in and around Siliguri, Jalpaiguri and Darjeeling attended the lecture. A number of teachers from schools, colleges and NBU were also present. It was an active interactive session, and at the end, the talk brought out the encouragement and enthusiasm among all. Another talk by Mangala Narlikar was organized by the IRC, and the Department of Mathematics, NBU jointly.

2. Lecture Series

A series of lectures by Kanak Saha (IUCAA) was organized by the IRC, NBU, at the following places: (i) NBU, on August 5, 2015, (ii) A. B. N. Seal College, Coochbehar, on August 11, 2015, (iii) Coochebehar College, on August 11, 2015, (iv) P.D. Women's College, Jalpaiguri, on August 12, 2015, and (v) St. Joseph College, Darjeeling, on August 13, 2015.

3. Winter School on General Relativity and its Applications

IUCAA sponsored Winter School on General Relativity and its Application was organized, during November 23 - 28, 2015. (Detailed report of this school could be found in IUCAA Quarterly Bulletin, KHAGOL, No. 105, January 2016, page 5.)

Seminars

- Jayant V. Narlikar (IUCAA), on Searches for life in our Universe.
- T. Padmanabhan (IUCAA), on Gravity and cosmos.
- Gobinda Majumdar (TIFR, Mumbai), on 2015 Noble Prize in Physics and Indian Neutrino Physics Programme.

Publications

IRC facilities have been used for the following publications:

- Bikash Chandra Paul, P.K. Chattopadhyay and S. Karmakar (2015) Relativistic anisotropic star and its maximum mass in higher dimension, Ap. Space Sci., 356, 327.

- Pragati Pradhan, Biswajit Paul, Harsha Raichur and Bikash Chandra Paul (2015) Variability of pulse profile of a rotation powered pulsar PSR B1509-58, Non-linear Dynamics and its Application, Published by Book Centre, page 240 [ISBN:978-81-921612-6-6].

- Pragati Pradhan, Biswajit Paul, Harsha Raichur and Bikash Chandra Paul (2015) Variations of the harmonic components of the X-ray pulse profile of PSR B1509-58, Res. Astron. Ap., 15, 28.

- Pragati Pradhan, Biswajit Paul, Bikash Chandra Paul, Enrico Bozzo and Tomaso M. Belloni (2015) Is 4U 0114+65 an eclipsing HMX ?, MNRAS (Accepted) [Doi:10.1093/mnras/stv2276].

- Bikash Chandra Paul (2015) An introduction to astronomical data analysis, Edited Book, Scholars' Press [ISBN 978-3-639-85990-4].

- Bikash Chandra Paul and S. Ghosh (2015) Estimation of observational constraints of the parameters in emergent universe model, An Introduction to Astronomical Data Analysis (Edited), Ch. 5, 96.

- Bikash Chandra Paul and P. Thakur (2015) Observational constraints on Chaplygin gas: A review, An Introduction to Astronomical Data Analysis (Edited), Ch. 7, 149.

- P. K. Chattopadhyay and Bikash Chandra Paul (2016) Density dependent B parameter of relativistic stars with anisotropy in pseudo-spheroidal spacetime, Ap. Space Sci., 361, 145.

- S. Das, R. Sharma, Bikash Chandra Paul and R. Deb (2016) Dissipative gravitational collapse of an (an)isotropic star, Ap. Space Sci., 361, 1.

- P. S. Debnath and Bikash Chandra Paul (2016) Viscous cosmologies with modified Chaplygin gas, Intl. J. App. Phys., 3, issue 2.

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-4Ganeshkhind Pune-7 Registration No. : F-5366 (PUNE) dated 27.1.1989

BALANCE SHEET AS ON 31ST MARCH 2016

Sr No.	FUNDS & LIABILITIES	Schedule No.	31.03.2016 Rs.
1	Trust Fund / Corpus	6	14,53,21,647
2	Grant-In-Aid from UGC	7	1,64,12,10,565
3	Other Project Grants	8	5,03,19,840
4	Projects and Other Payable (Net)	9	6,79,67,768
5	Current Liabilities	10 & 10A	4,00,81,907
6	Income and Expenditure a/c	14	(17,50,26,757)
	Total		**1,76,98,75,170**

Sr No.	ASSETS & PROPERTIES	Schedule No.	31.03.2016 Rs.
1	Fixed Assets	11	1,13,09,59,486
2	Investments / Deposits	12	39,26,23,075
3	Project & Other Receivables (net)	13	1,03,69,873
4	Current Assets -	13	
	a) Cash, Bank balances & Revenue Stamps		2,61,97,445
	b) Loans and Advances	13A	20,27,92,370
	c) Deposits		23,32,016
	d) Prepaid Expenses		38,77,968
	e) Advance to Suppliers	13B	7,22,937
	Total		**1,76,98,75,170**

For Inter-University Centre for Astronomy & Astrophysics

As per Report of even date
For Kirtane & Pandit LLP
Chartered Accountants
FRN- 105215W/W100057

M.S.Sahasrabudhe
Admin. Officer (Accounts)

N. V. Abhyankar
(Sr.Admin.Officer)

Parag Pansare
(Partner)
Membership No.117309

Place : Pune
Date : 14.06.2016

Prof. Somak Raychaudhury
(Director / Trustee)

Chairperson
Governing Board

IUCAA, Post Bag 4, Ganeshkhind, Pune 411 007, India.
Location : Meghnad Saha Road, S. P. Pune University Campus, Ganeshkhind, Pune 411 007, India
Phone : (91) (20) 2560 4100 Fax : (91) (20) 2560 4699
e-mail : publ@iucaa.in
Universal Resource Locator (URL) : http://www.iucaa.in