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April 1, 2014 - March 31, 2015

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

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THE COUNCIL AND THE GOVERNING BOARD

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(As on March 31, 2015)

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Wasudeo N. Gade

Swarna Kanti Ghosh

Arun Kumar Grover

S. V. Raghavan

Varun Sahni

Ajit K. Kembhavi
(Member Secretary)

Manju Singh
(Special Invitee)

The following member has served on the Governing Board for part of the year.

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Vice-Chancellor,
University of Hyderabad.

The following members have served on the Council for part of the year.

Asoke Kumar Sen,
Department of Physics,
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T. P. Prabhu,
Indian Institute of Astrophysics,
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Mihir Choudhuri,
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S. K. Pandey,
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University of Amsterdam,
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Antony Hewish,
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Yash Pal,
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Mumbai University Campus,
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Institute for Gravitation and the Cosmos, Pennsylvania State University, USA.

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Tata Institute of Fundamental Research, Mumbai.

Andrew C. Fabian,
University of Cambridge,
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Yashwant Gupta,
National Centre for Radio Astrophysics, Pune.

Romesh Kaul,
The Institute of Mathematical Sciences, Chennai.

Ajit K. Kembhavi,
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IUCAA, Pune.

P. N. Pandita,
North Eastern Hill University,
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Martin M. Roth,
Astrophysikalisches Institut,
Potsdam, Germany.

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Dipankar Bhattacharya,
IUCAA, Pune.

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Tezpur University.

Sarbari Guha,
St. Xavier's College, Kolkata

M. K. Patil,
Swami Ramanand Teerth Marathwada University, Nanded.

T. Ramachandran,
Vice-Chancellor,
Cochin University of Science and Technology, Kochi.

Indra Vardhan Trivedi,
Vice-Chancellor,
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Joydeep Bagchi

Dipankar Bhattacharya

Sukanta Bose

Gulab Chand Dewangan

Neeraj Gupta

Ranjan Gupta

Ranjeev Misra

Sanjit Mitra

Aseem S. Paranjape
(Joined on 15.09.2014)

A. N. Ramaprakash

Swara Ravindranath
(Resigned on 31.05.2014)

Kanak Saha

Varun Sahni

Tarun Souradeep

R. Srianand

Durgesh Tripathi

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(Member Secretary)

T. Padmanabhan

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(Chairperson)

Niranjan V. Abhyankar
(Non-member Secretary)

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Ajit K. Kembhavi

Varun Sahni

Jaspal Singh Sandhu

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(Director)

T. Padmanabhan
(Dean, Core Academic Programmes)

Kandaswamy Subramanian
(Dean, Visitor Academic Programmes)

Joydeep Bagchi

Dipankar Bhattacharya

Sukanta Bose

Gulab Chand Dewangan

Neeraj Gupta

Ranjan Gupta

Ranjeev Misra

Sanjit Mitra

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(Resigned on 31.05.2014)

Kanak Saha

Varun Sahni

Tarun Souradeep

R. Srianand

Durgesh Tripathi

EMERITUS PROFESSORS

Naresh K. Dadhich

Sanjeev V. Dhurandhar

Jayant V. Narlikar

Shyam N. Tandon

SCIENTIFIC AND TECHNICAL

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Nirupama U. Bawdekar

Rani S. Bhandare

Santosh S. Bhujbal

Mahesh P. Burse

Kalpesh S. Chillal

Pravinkumar A. Chordia

Hillol K. Das

Samir A. Dhurde

Gajanan B. Gaikwad

Sudhakar U. Ingale

Santosh B. Jagade
(Joined on 14.07.2014)

Pravin V. Khodade

Abhay A. Kohok

Vilas B. Mestry

Shashikant G. Mirkute

Deepa Modi

Vijay Mohan

N. Nageswaran

Nitin D. Ohol

Sarah Ponrathnam

Swapnil M. Prabhudesai

Sujit P. Punnadi

Vijay Kumar Rai

Chaitanya V. Rajarshi

Hemant Kumar Sahu

Yogesh R. Thakare

Ajay M. Vibhute
(Joined on 07.07.2014)

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(Senior Administrative Officer)

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Rahul S. Gaikwad

Sandeep L. Gaikwad

Bhagiram R. Gorkha

Bhimpuri S. Goswami

Prashant S. Jadhav

Ramesh S. Jadhav

Sandip M. Jogalekar

Nilesh D. Kadam

Swati D. Kakade

Santosh N. Khadilkar

Murli N. Krishnan

Neelima S. Magdum

Manjiri A. Mahabal

Kumar B. Munuswamy

Rajesh D. Pardeshi

Rajesh V. Parmar

Mukund S. Sahasrabudhe

Vyankatesh A. Samak

Senith S. Samuel

Balaji V. Sawant

Deepak R. Shinde

Shahish K. Sukale
(Joined on 09.06.2014)

Varsha R. Surve

Deepika M. Susainathan

Shashank S. Tarphe

Shankar K. Waghela

Kalidas P. Wavhal

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Prasanta Bera
Pallavi Bhat
Sumanta Chakraborty
Kabir Chakravarti
Luke Chamandy
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Santanu Das
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Suprit Singh
Akshat Singhal
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Aparna Venkataramanasastry

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Bhavana Bhojgar
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V. Chellathurai
Gaurav S. Datir
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Moin Shaikh
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Kirti Tonpe

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Anjan Ananda Sen, Centre for Theoretical Physics, Jamia Millia Islamia, New Delhi
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Somasri Sen, Department of Physics, Jamia Millia Islamia, New Delhi
Anand Sengupta, Department of Physics, IIT Gandhinagar, Ahmedabad
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K. Shanthi, UGC Human Resource Development Centre, University of Mumbai, Kalina
Ranjan Sharma, Department of Physics, P.D. Women's College, Jalpaiguri
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L. Sriramkumar, Department of Physics, IIT Madras, Chennai
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Paniveni Udayashankar, Department of Physics, NIE Institute of Technology, Mysore
Anisul Ain Usmani, Department of Physics, Aligarh Muslim University, Aligarh

From August 2014

Sarmistha Banik, Department of Physics, BITS - Pilani, Hyderabad
Archana Bora, Department of Physical Sciences , Gauhati University, Guwahati
Ritaban Chatterjee, Department of Physics, Presidency University, Kolkata
Suchetana Chatterjee, Department of Physics, Presidency University, Kolkata
Dhurjati Prasad Datta, Department of Mathematics, University of North Bengal, Siliguri
Titus K. Mathew, Department of Physics, Cochin University of Science and Technology, Kochi
Irom Ablu Meitei, Department of Physics, Modern College, Imphal
Hameeda Mir, Department of Physics, Government Sri Pratap College, Srinagar, Jammu and Kashmir
Dibyendu Nandi, Centre of Excellence in Space Science, IISER, Kolkata.
Rahul Nigam, Department of Physcis, BITS - Pilani, Hyderabad
Surajit Paul, Department of Physics, Savitribai Phule Pune University
Saumyadip Samui, Department of Physics, Presidency University, Kolkata
Gargi Shaw, Centre for Excellence in Basic Sciences, University of Mumbai, Kalina Campus
Vikram Soni, Centre for Theoretical Physics, Jamia Millia Islamia, New Delhi
K. Sriram, Department of Astronomy, University College of Science, Osmania University, Hyderabad
Arun Varma Thampan, Department of Physics, St. Joseph's College, Bengaluru

VISITING ASSOCIATES

The Twenty-Fifth batch (2014) of visiting associates, who were selected for a tenure of three years, beginning August 1, 2014.

ARCHANA BORA

ARUN V. THAMPAN

GARGI SHAW

HAMEEDA MIR

IROM ABLU MEITEI

K. SRIRAM

DIBYENDU NANDI

RAHUL NIGAM

RITABAN CHATTERJEE

SUCHETANA CHATTERJEE

SARMISTHA BANIK

SAUMYADIP SAMUI

SURAJIT PAUL

TITUS K. MATHEW

VIKRAM SONI

DHURJATI PRASAD DATTA

Appointments of the following Visiting Associates of the Twenty-second batch have been extended for three years : Bijan Kumar Bagchi, Naseer Iqbal Bhat, Vasudha Bhatnagar, Shuvendu Chakraborty, Ramesh Chandra, Suresh Chandra, Asis Kumar Chattopadhyay, Surajit Chattopadhyay, Tanuka Chattopadhyay, Rabin Kumar Chhetri, Sudipta Das, Ujjal Debnath, Jishnu Dey, Mira Dey, Sunandan Gangopadhyay, Suresh Kumar, V.C. Kuriakose, Manzoor Malik, Soma Mandal, Pradip Mukherjee, S.K. Pandey, Kishor Dnyandeo Patil, Ninan Sajeeth Philip, Shantanu Rastogi, Saibal Ray, Sanjay Baburao Sarwe, Anand Sengupta, and T.R. Seshadri,

AWARDS AND RECOGNITIONS

Varun Bhalerao

INSPIRE Faculty Award by the Department of Science and Technology, Government of India, New Delhi.

Sumanta Chakraborty

Professor Satyendra Nath Bose Memorial Prize 2013 on securing highest marks in M.Sc. Part-II Physics examination, University of Calcutta.

Sujan Kumar Seal Memorial Scholarship 2012-13, University of Calcutta for M.Sc. degree in Physics with highest marks.

Dipankar Bhattacharya

Fellow, National Academy of Sciences, India.

Jayant Narlikar

Sahitya Akademi Award for his autobiography in Marathi entitled 'Chaar Nagarantale Maaze Vishwa', March 9, 2015.

Lifetime Achievement Award from the Union Bank of India, November 11, 2014.

T. Padmanabhan

Goyal Prize in Physical Sciences 2012-13, Kurukshetra University.

Varun Sahni

Homi Jehnagir Bhabha Medal 2014, Indian National Science Academy, New Delhi.

Neeraj Gupta

DST Start-up Research Grant for the project "Evolution of Cold Gas in Galaxies using Absorption Lines".

Sandipan Sengupta

N. R. Sen Young Researcher Award 2015, Indian Association for General Relativity and Gravitation

ORGANISATIONAL STRUCTURE

THE DIRECTOR

Ajit K. Kembhavi

Dean, Core Academic Programmes	T. Padmanabhan
Dean, Visitor Academic Programmes	K. Subramanian
Head, Computing Facilities	Dipankar Bhattacharya
Head, Public Outreach Programmes	Durgesh Tripathi / Sanjit Mitra
Head, IUCAA Girawali Observatory	Vijay Mohan / Ranjan Gupta
Head, Scientific Meetings	Ranjan Gupta
Head, Publications	Swara Ravindranath / Ajit Kembhavi
Head, Estate Development and Maintenance	Ajit Kembhavi
Head, Instrumentation	A. N. Ramaprakash
Head, IUCAA Resource Centres	Ranjeev Misra
Head, Library	Varun Sahni
Head, Infrastructural Facilities	Tarun Souradeep
Head, Teaching Programmes	R. Srianand
Head, Observing Programmes and SALT	R. Srianand

DIRECTOR'S REPORT

I am glad to say that during 2014 -15, IUCAA has progressed substantially on all fronts of its activities. The faculty members have been engaged in research and development, teaching at the IUCAA – NCRA graduate school and on various university campuses, thesis supervision, and organization of workshops and other meetings at IUCAA and other campuses. During this year, Aseem Paranjape has joined as a faculty member. He specializes in cosmology and gravitation with particular interest in large scale structure, galaxy clusters, dark energy, and N-body simulations. At present, IUCAA has 18 faculty members, including the Director, 22 post-doctoral fellows, including three DST – INSPIRE faculty fellows, and 39 research scholars, including four CSIR – SPM scholars. In addition, there have been several long term senior visiting and emeritus professors. In this year, academic members have published about 170 research papers in high impact, national and international journals.

The 11 m Southern African Large Telescope (SALT) located near the town of Sutherland in South Africa, of which IUCAA is a part owner, is being used for spectroscopic observations by astronomers from IUCAA and universities. Interesting results have been obtained and several research papers have been published from these observations. Members working on the Virtual Observatory project at IUCAA have developed a sophisticated data archival system for SALT in collaboration with astronomers from the South African Astronomical Observatory at Cape Town.

The 2 m optical and near-infrared telescope at IUCAA Girawali Observatory (IGO), which had been functioning very productively over the last several years, has had a series of problems, primarily due to the aging telescope hardware, computer systems and software. Routine repair of these parts or their replacement is proving to be difficult, because the company that built the telescope for IUCAA no longer exists. While it is possible to keep the telescope operational even in these difficult circumstances, it has been decided to carry out major refurbishment to make it more robust and reliable, and to make it possible to use the telescope remotely and robotically. Such facilities are essential for the observation of transient sources, amongst other objects of interest, which are of great importance in contemporary astronomy. The refurbishment will be carried out by the IUCAA instrumentation laboratory with the help of outside experts and consulting engineers. Arrangements are also being made for the long term maintenance of the telescope.

IUCAA members have contributed significantly to the development of hardware and software for ASTROSAT, which is expected to be launched by ISRO in the second quarter of 2015. The development of the Ultra-Violet Imaging Telescope (UVIT), to be carried by the ASTROSAT, has been completed at the Indian Institute of Astrophysics (IIA), Bengaluru by Shyam Tandon of IUCAA in the lead. IUCAA has helped with the calibration of the CZTI instrument, and is preparing to be a Payload Operations Centre (POC) for CZTI data. Preparations are being made to set up a National ASTROSAT Science Facility at IUCAA with the help of ISRO. This will help faculty and students from universities and institutes in the country to carry out analysis of the data obtained by ASTROSAT.

During 2014 - 15, IUCAA had 115 visiting associates from universities and colleges. Many of them spend significant periods at IUCAA, often accompanied by their research students. They have been using the IUCAA facilities, and collaborate with IUCAA faculty members as well as with other associates and visitors, to carry out quality research. During the year the visiting associates and their students have published about 240 research papers in high impact national and international journals. About 20 research students from universities have used the facilities of IUCAA and completed a significant part of their Ph.D. research work under the supervision of IUCAA faculty members.

The IUCAA Resource Centres (IRCs) at Delhi, Kochi, Kolkata, Raipur, Siliguri, and Udaipur have been working hard to reach the goals for which these were set up. Apart from IRCs, there are IUCAA Nodes for Astronomy and Astrophysics Development (INAADs) and IUCAA University Centres at various locations, which cater to the needs of the local researchers and students. A number of programmes for universities and colleges have been organized at IUCAA, IRCs and elsewhere, and reports on these are given later in this publication.

During the year, IUCAA has conducted a number of national and international workshops, schools and conferences, covering a number of fields of interest on the IUCAA campus as well as at other centres. These include an International Conference on Coupling and Dynamics of the Solar Atmosphere, Workshop on RoboPol and Polarimetry in Astronomy, Winter School on the Central Region of Spiral Galaxies, an India - South Africa Flagship Meeting, and a SALT Science Symposium, which were all conducted at IUCAA.

Much progress has been made on the LIGO – India project for the installation of an advanced laser interferometer gravitational wave detector in India, in collaboration with LIGO – USA. After having gone through several stages of positive recommendations, the project is now at the final stages of approval by the Government of India. The site selection process has been making steady progress with the help of seismologists, consulting engineers and other experts. A few sites have been shortlisted, and the final site selection is expected to take place soon.

The Thirty Metre Telescope (TMT) project, of which IUCAA is a lead institute along with Indian Institute of Astrophysics, Bengaluru and ARIES, Nainital, is also making a steady progress. One of IUCAA's responsibilities has been the development of the Telescope Control System software. IUCAA is also involved with the development of hardware related to the primary mirror system and scientific instrumentation and science projects for the TMT.

Plans have been drawn up for the construction of a new office block along with lecture halls and laboratory complex. This will house the centres to carry out the LIGO – India and TMT projects as well as the National ASTROSAT Science Facility.

The National Science Day was celebrated on February 28, 2015 by having an open house for the public of Pune and the surrounding places. There were lectures, demonstrations, exhibitions, poster displays and question-answer sessions throughout the day; in the night there was a sky watching programme, which as always had long queues of people to look through the telescopes. In the preceding week, various science oriented competitions were conducted separately for school students from rural and urban areas. There were tough competitions for some of the events, and the winners were given prizes and appreciation certificates.

All the exciting work being done at IUCAA has been possible because of the many talents and sincere efforts of its academic, scientific, technical, administrative and contractual staff. I say THANK YOU to all of them for their fine contributions and collective efforts. I wish to thank the Governing Board members, and in particular, the Chairperson, Dr. Srikumar Banerjee, for his constant support and encouragement to IUCAA, and to me personally. I also thank the President of the Council and Chairman, University Grants Commission, Professor Ved Prakash and other Council Members for their full support and co-operation, especially in critical situations. Our objectives would not have been achieved without the help and counsel provided by the University Grants Commission and its officers and staff.

Ajit Kembhavi
Director

ACADEMIC CALENDAR

Events Outside IUCAA

2014

June 15 - July 5
Astronomy and Astrophysics Summer School
at Cotton College State University, Guwahati

August 21 - 23
Introductory Workshop in Relativistic Astrophysics
at Gauhati University, Guwahati
Coordinators: Ranjeev Misra and Sanjeev Kalita

September 4 - 6
Introductory Workshop on Recent Trends in Astrophysics and Cosmology
at MCNS, Manipal University
Coordinators: Debbijoy Bhattacharya and Ranjeev Misra

September 26 - 27
Workshop on Basic Astronomy and Telescope Making (for School students)
at Kohima Science College, Nagaland

November 25 - 28
Workshop on Active Galaxies: An X-ray and Radio View
at SRTM University, Nanded
Coordinators: Madhav K. Patil and Gulab Dewangan

November 25 - 27
Workshop on Current Trends in Near Infrared Astronomy in India
at TIFR Balloon Facility, Hyderabad
Coordinators: D.K. Ojha, Ranjan Gupta and G.C. Anupama

December 15 - 18
International Conference on Interstellar Dust, Molecules and Chemistry (IDMC - 2014)
at Tezpur University
Coordinators: Ranjan Gupta, Gazi Ameen Ahmed, Amit Pathak and Shantanu Rastogi

2015

January 5 - 9
Workshop on Cosmology with Large Scale Structures
at Jamia Millia Islamia, New Delhi
Coordinators: Anjan Ananda Sen and R. Srianand

January 19 - 20
Workshop on Solar Astrophysics
at Regional Science Centre and Planetarium, Kozhikode
Coordinator: Durgesh Tripathi, Jayant Ganguly and Mini P. Balakrishnan

February 10 - 13
Workshop on Statistical Applications to Cosmology and Astrophysics
at Indian Statistical Institute, Kolkata
Coordinators: Supratik Pal and Tarun Souradeep

March 13 - 14
Workshop on Intrdoductory Astronomy And Astrophysics
at Jagannath Barooah College, Jorhat, Assam.
Coordinators : Ranjeev Misra and Ankur Gogoi

ACADEMIC CALENDAR

IUCAA Events

2014

April 22 - May 23
School Students' Summer Programme and Summer Astronomy Camp

May 5 - June 6
Introductory Summer School in Astronomy and Astrophysics
(for College and University Students)

May 5 - June 20
Vacation Students' Programme

September 8 - 12
Workshop on Fabrication of Night Sky Photometer for Small Telescopes
Coordinator: Ranjan Gupta

November 10 - 14
International Conference on Coupling and Dynamics of the Solar Atmosphere
Coordinator: Durgesh Tripathi

December 22 - 31
Radio Astronomy Winter School
at IUCAA and NCRA, Pune.
Coordinators: Joydeep Bagchi and B.C. Joshi

2015

January 6 - 7
Workshop on RoboPol and Polarimetry in Astronomy
Coordinator: A.N. Ramaprakash

January 12 - 23
Winter School on the Central Region of Spiral Galaxies.
Coordinator: Kanak Saha

February 16
Satellite Workshop on Multi-wavelength Astronomical Data, Analysis, Visualization and the Virtual Observatory : Pre-ASI 2015 Meeting
Coordinators: Ajit Kembhavi and Ranjeev Misra

February 18
Calibration of Samrat Yantra: Part of ASI 2015 Meeting

September 19
India-South Aftica Flagship Meeting

November 17 - 20
SALT Science Symposium and Board Meeting

IUCAA Resource Centre Events

2014

September 4 - 5
INAAD Introductory Workshop on Cosmology
at Sri Venlateswara College, Delhi
Coordinators: Pranjal Trivedi and T.R.Seshadri

September 10 - 13
Workshop on Cosmology
at S.H. College, Thevara, Kochi
Coordinators: Issac Kuriakose and V.C. Kuriakose

November 3 - 4
Workshop on Observational Aspects of Astrophysical and Cosmology
at Visva-Bharati University, Santiniketan
Coordinators: Sudipta Das and Biswajit Pandey

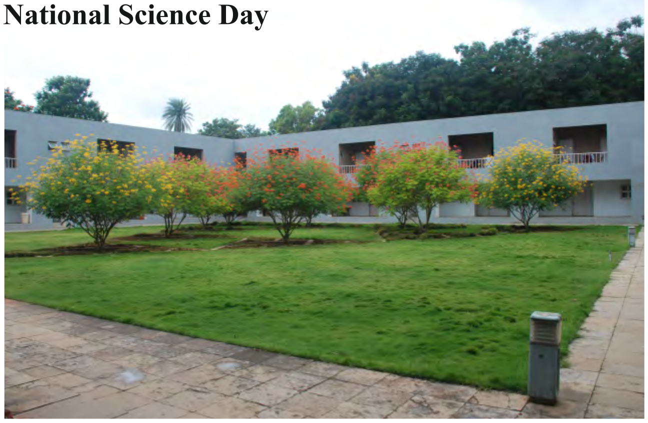
IUCAA Annual Events

2014

December 29
Foundation Day Silver Jubilee Lecture

2015

February 28
National Science Day



RESEARCH AT IUCAA

Quantum Theory and Gravity

Null surfaces: Counter-term for the action principle and the characterization of the gravitational degrees of freedom

It is common knowledge in the community that imposing consistent boundary conditions to obtain Einstein's equations from the variation of the Einstein-Hilbert action is a non-trivial matter. The accepted solution is to add an extra term, the Gibbons-Hawking-York counter-term, to the action and vary the new action obtained. Then, if the induced metric on the boundary is fixed, we obtain Einstein's equations. Although, this procedure works very well when the boundary is a spacelike or timelike surface, as the Gibbons-Hawking-York counter-term by itself cannot be used on a null surface. Generally, people get around this difficulty by evaluating the term for a timelike or spacelike surface and then taking the appropriate limit of some parameter to make this surface null.

Krishnamohan Parattu, with **Sumanta Chakraborty**, Bibhas Ranjan Majhi and **T. Padmanabhan**, decided to investigate and find out the counterpart of the Gibbons-Hawking-York counter-term that could be added to the action, so that its variation is well-defined when the boundary is null. In a particular parametrization of the metric near a null surface, they obtained the required counter-term by analyzing the structure of the boundary term in the variation of the Einstein-Hilbert action. Later, they were able to remove the crutches of the parametrization and write this result in geometrical terms. In the course of this analysis, they also found that there were six degrees of freedom in the metric whose variations appeared in the boundary term on the null surface, but also that three of these could be eliminated by making use of diffeomorphisms on the null surface. Thus, they were able to localize the degrees of freedom that were to be fixed on the boundary null surface for Einstein-Hilbert action to the three degrees of freedom in the 2-metric, q_{ab}, on the null surface.

Einstein-Hilbert action: The structure of the boundary term and the counter-term for a general surface

Having obtained a counter-term for null boundaries, **Krishnamohan Parattu**, with **Sumanta Chakraborty** and **T. Padmanabhan** attempted a more general analysis. They started from first principles and proposed a counter-term that can be used to eliminate variations of the "off-the-surface" derivatives of the metric on any boundary, regardless of its spacelike, timelike or null nature. Further, they analyzed the degrees of freedom that need to be fixed on a boundary surface and reproduced standard results in the literature.

Gravitational field equations near an arbitrary null surface expressed as a thermodynamic identity

Previous work had demonstrated that the gravitational field equations in the near-horizon limit in static spacetimes imply a thermodynamic identity $T\delta_\lambda S = \delta_\lambda E + P\delta_\lambda V$ in all Lanczos-Lovelock models. **Sumanta Chakraborty**, with **Krishnamohan Parattu** and **T. Padmanabhan**, generalized this result to any arbitrary null surface in an arbitrary spacetime in general relativity, and showed that certain components of the Einstein's equations can be expressed in the form of the above thermodynamic identity. In the process, they obtained an explicit expression for the thermodynamic energy associated with the null surface. Under appropriate limits, the expressions reduced to those previously derived in the literature. Finally, they showed how the different results available in the literature can be described in terms of three well-defined projections of Einstein's equations near a null surface.

Evolution of spacetime and holographic equipartition: Lovelock gravity

In the case of general relativity, one can interpret the Noether charge in any bulk region as the heat content TS of its boundary surface. Moreover, the time evolution of spacetime metric in Einstein's theory arises due to the difference $(N_{sur} - N_{bulk})$ of suitably defined surface and bulk degrees of freedom. Both of these results were derived by **T. Padmanabhan** in the context of general relativity in a recent work. However, it is natural to ask, whether these results hold only in general relativity or in more general class of theories. The most natural candidate for generalization of general relativity is Lovelock gravity, since the field equation remains second order in the dynamical variable. In a recent work **Sumanta Chakraborty** and **Padmanabhan** have shown that this thermodynamic interpretation generalizes in a natural fashion to all Lovelock models of gravity. Foliating the spacetime in usual manner with u_a being normal to t = constant surface, we get the time evolution vector field $\xi^a = Nu^a$, where N is the lapse function. The Noether charge, related to time evolution vector field ξ^a, in a bulk region $\mathcal{V}$ of space with boundary $\partial\mathcal{V}$ is equal to the heat content TS of the boundary surface:

$$\int_{\mathcal{V}} d^{D-1}x\sqrt{h}u^a J_a(\xi) = \int_{\partial\mathcal{V}} d^{D-2}x\; T_{\rm loc}s\;.$$

The temperature $T_{\rm loc}$ in the above expression is defined using local Rindler observers and s being the Wald entropy density.

Using the Wald entropy, we can define the surface degrees of freedom N_{sur} and Komar energy density to define the bulk degrees of freedom, N_{bulk}. With the help of these two degrees of freedom, we can also show that the time evolution of the geometry is sourced by $(N_{sur} - N_{bulk})$:

$$\int_{\mathcal{V}} \frac{d^{D-1}x\sqrt{h}}{8\pi} \times 2u_a P_i^{\ jka} \pounds_\xi \Gamma^i_{jk} = \left(\frac{1}{2}T_{\rm avg}\right)(N_{sur} - N_{bulk})\,.$$

Here T_{avg} is the average Davies-Unruh temperature of the boundary $\mathcal{V}$, Γ^i_{jk} is the standard metric compatible connection and $P_i^{\ jka}$ is the entropy tensor in Lovelock gravity. When it is possible to choose the foliation of spacetime such that metric is independent of time, the above dynamical equation yields the holographic equipartition for Lanczos-Lovelock gravity with $N_{sur} = N_{bulk}$. Thus, we conclude that it is the departure from this holographic equipartition that drives the spacetime evolution. This result holds not only in general relativity but also in Lovelock gravity.

Geometrical variables with thermodynamic interpretation

The link between the standard approach to gravity and the thermodynamical one is provided by the action principle of gravity. Previous studies have shown that these actions have several peculiar features, and under suitable conditions, a thermodynamical interpretation. This motivates us to look for geometrical variables in which the expression for action simplifies and have direct thermodynamical interpretation. More specifically, we want to discover geometrical variables, symbolically called $[q,p]$ such that $q\delta p$ and $p\delta q$ will correspond to $s\delta T$ and $T\delta s$, where T is the horizon temperature and s is the entropy density.

It has been shown in an earlier work by **Krishnamohan Parattu**, Bibhas Ranjan Majhi and **T. Padmanabhan** that there exists a pair of canonically conjugate variables (f^{ab}, N^a_{bc}) in general relativity, which also act as thermodynamically conjugate variables on any null surface. In particular, their variations $(f^{bc}\delta N^a_{bc}, N^a_{bc}\delta f^{bc})$, which occur in the surface term of the Einstein-Hilbert action, when integrated over a null surface, have direct correspondence with $s\delta T, T\delta s)$ where (T,s) are the temperature and entropy. This was also done in the framework of general relativity. Thus, it is pertinent to ask whether such geometrical variables with thermodynamic interprtation exists in Lovelock gravity as well.

In a recent work **Sumanta Chakraborty** and **Padmanabhan** have shown that these variables can be generalized to Lovelock gravity models. We identify two such variables in Lovelock models such that (a) our results reduce to that of general relativity in the appropriate limit, and (b) the variation of the surface term in the action, when evaluated on a null surface, has direct thermodynamic interpretation as in the case of general relativity. The variations again correspond to $s\delta T$ and $T\delta s$, where s is now the appropriate Wald entropy for the Lanczos-Lovelock model. The analysis once again confirms that the thermodynamic interpretation goes far deeper than general relativity and is definitely telling us something non-trivial about the structure of the spacetime. We note that the nature of Wald entropy density in Lovelock models is far more complicated than a simple constant (1/4) in general relativity; yet, everything works out exactly as expected. The action principle somehow encodes the information about horizon thermodynamics, which is a key result in emergent gravity paradigm.

Black hole kinematics

It is well-known that the asymptotic observers see a thermal flux with temperature $T_H = (1/8\pi)M$ being radiated from the black hole horizon. However, we can have non-asymptotic observers and the energy density, and flux will be different for each of them depending on their trajectories. There have been many attempts to answer the question, What do these non-asymptotic observers see? Most of the answers stop at the horizon and one would like to know what happens on the inside too.

Suprit Singh and **Sumanta Chakraborty** have taken up this issue and have investigated the local invariant scalar observables - energy density and flux - which explicitly depend on the kinematics of the concerned observers in the thin null shell gravitational collapse geometry. The use of globally defined null coordinates allows for the definition of a unique in-vacuum for the scalar field propagating in this background (see Figure 1). Computing the stress-energy tensor for this scalar field, we work out the energy density and flux for the static observers outside the horizon (see Figure 2), and then consider the radially in-falling observers who fall in from some specified initial radius all the way through the horizon and inside to the eventual singularity (see Figure 3). Our results confirm the thermal Tolman-shifted energy density and fluxes for the static observers which diverge at the horizon. For the in-falling observer starting from far off, both the quantities – energy density and flux at the horizon crossing are *regular and finite*. For example, the flux at the horizon for the in-falling observer from infinity is approximately 24 times the flux for the observer at infinity. Compared with the static observers in the near-horizon region, this is quite small. Both the quantities grow as the in-fall progresses inside the horizon and diverge at the singularity.

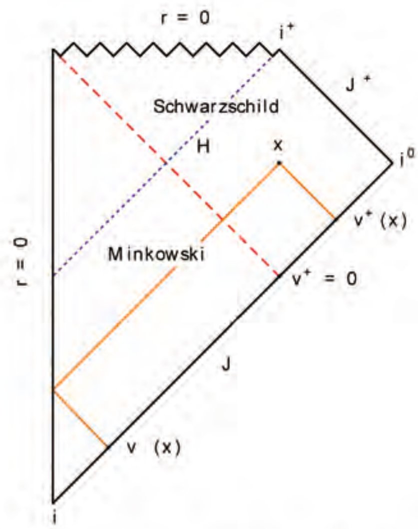


Figure 1: Penrose diagram for the Vaidya spacetime with two regions - Minkowski (interior) and Schwarzschild (exterior) separated by null thin-shell (dashed) at $v = 0$. The dotted line denotes the event horizon $\mathcal{H}$. Any event x on the spacetime can be labelled by two globally defined null coordinates (v^+, v^-), which correspond to a null ray coming directly from $\mathcal{J}^-$ and a null ray traced back in the past to the vertical line $(r = 0)$ and then reflected off to $\mathcal{J}^-$ respectively.

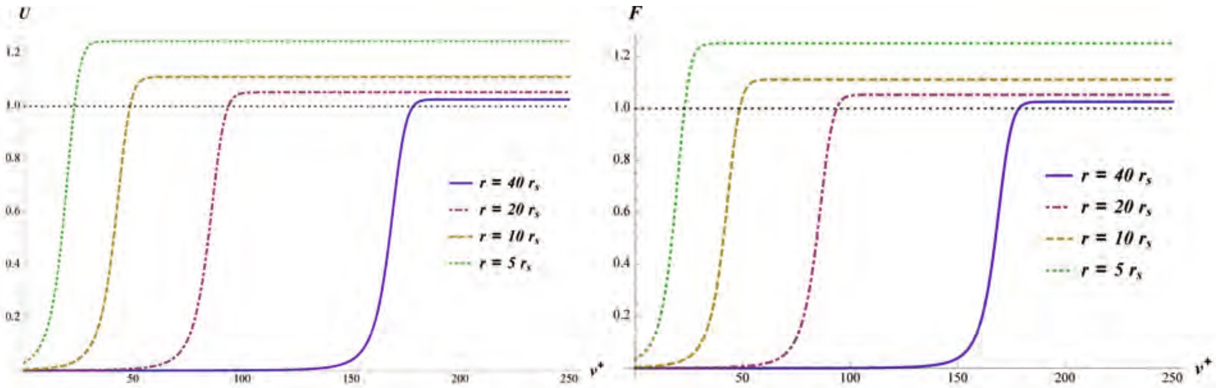


Figure 2: The figures show energy densities (U) and fluxes (F) perceived by a static observers specified by their radial positions along their trajectory as a function of v^+, which is proportional to the proper time. Both U and F are normalized to their value at infinity, $\pi T_H^2/12$ and we have taken $M = 1$ so that $r_s = 2$ in our case. The energy density and flux show similar behaviour of growing slowly early on and later making a transition to saturated thermal state for larger radii.

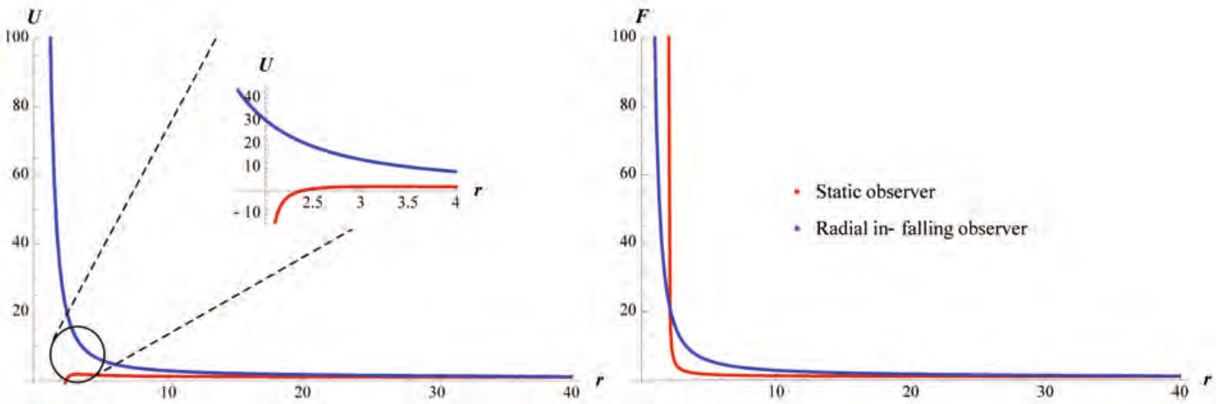


Figure 3: The plots show energy density (U) and flux (F) perceived by a radially in-falling observer normalized by $\pi T_H^2/12$ with $M = 1$ so that $r_s = 2$. The figures compare U and F for the in-falling observer from $r_i = 20\,r_s$ with those observed by the thermal static observers at different radii.

Anomalous effective action, Noether current, Virasoro algebra and horizon entropy

It has been known for a while that in a very small length scale, there exists corrections to the entropy of black hole horizon. Due to fluctuations of the background metric and the external fields, the action incorporates corrections. In the low energy regime, the one loop effective action in four dimensions leads to trace anomaly. In a recent work **Sumanta Chakraborty**, with Bibhas Ranjan Majhi has shown that for Einstein-Hilbert action plus the one loop effective action does not modify the usual expression for entropy; i.e., the Bekenstein-Hawking form.

In this work, we have evaluated the general expressions explicitly for the anomaly induced action which produces the type-A trace anomaly. This action has a pure geometric meaning except the Euler characteristics and couplings appearing in it. For this particular action, we have shown that the Fourier modes of the bracket is similar to the usual Virasoro algebra with central extension. Identifying the central charge and the zero mode eigenvalue and then using them in the Cardy formula, we obtained the expression for the entropy, from which we have observed that there is no correction term to Bekenstein-Hawking entropy present.

Equilibrium configurations of perfect fluid in alternative gravity theories

Sumanta Chakraborty has investigated the hydrodynamic behaviour of perfect fluid orbiting around black holes in spherically symmetric spacetime for various alternative gravity theories. For this purpose, he has assumed an uniform distribution for the angular momentum density of the rotating perfect fluid. The contours of equipotential surfaces are illustrated in order to obtain the nature of inflow and outflow of matters. It has been noticed that the marginally stable circular orbits originating from decreasing angular momentum density lead to closed equipotential surfaces along with cusp allowing existence of accretion disks. On the other hand, the growing part of angular momentum density exhibits central rings for which stable configurations are possible. However, inflow of matter is prohibited. Among the solutions discussed in this work, the charged $F(R)$ gravity and Einstein-Maxwell-Gauss-Bonnet solution exhibit inflow and outflow of matter with central rings. These varied accretion disk structure of perfect fluid attribute these spacetimes astrophysical importance. The effect of higher curvature terms predominantly arises from region near the black hole horizon. Hence, the structural difference of accretion disk in modified gravity theories with comparison to general relativity may act as an experimental probe for these alternative gravity theories.

Various aspects of brane world models and phenomenology

Sumanta Chakraborty, along with Soumitra SenGupta has presented a general formalism to analyze a generic bulk scalar field in a multiple warped extra-dimensional model with arbitrary number of extra dimensions. The Kaluza-Klein (KK) mass modes along with the self-interaction couplings are determined and the possibility of having lowest lying KK mode masses near TeV scale are discussed. Also some numerical values for low-lying KK modes have been presented showing explicit localization around TeV scale. It is argued that the appearance of large number of closely spaced KK modes with enhanced coupling may prompt possible new signatures in collider physics.

In a recent work, they have investigated brane-world models in different viable $f(R)$ gravity theories, where the Lagrangian is an arbitrary function of the curvature scalar. Deriving the warped metric for this model, resembling Randal-Sundrum (RS) like solutions, we determine the graviton KK modes. The recent observations at the LHC, which constrain the RS graviton KK modes to a mass range greater than 3 TeV, are incompatible to RS model predictions. It is shown that the models with $f(R)$ gravity in the bulk address the issue which in turn constrains the $f(R)$ model itself.

They have also solved the Einstein's equation in five-dimensional spacetime for Randall Sundrum brane world model with time dependent radion field to study variation of brane scale factor with time. They have shown that as radion field decreases with time compactifying the extra dimension, the scale factor increases exponentially with time leading to inflationary scenario. They have also proposed a time dependent generalization of Goldberger-Wise moduli stabilization mechanism to explain the time evolution of the radion field to reach a stable value after which the scale factor on the brane exits from inflationary expansion.

Introducing $f(R)$ term in the five-dimensional bulk action, **Chakraborty** with SenGupta has derived effective Einstein's equation on the brane using Gauss-Codazzi equation. This effective equation is then solved for different conditions on dark radiation and dark pressure to obtain various spherically symmetric solutions. Some of these static spherically symmetric solutions correspond to black hole solutions, with parameters induced from the bulk. Specially, the dark pressure and dark radiation terms (electric part of Weyl curvature) affect the brane spherically symmetric solutions significantly. They have solved for one parameter group of conformal motions, where the dark radiation and dark pressure terms are exactly obtained by exploiting the corresponding Lie symmetry. Various thermodynamic features of these spherically symmetric spacetimes are studied, showing existence of second order phase transition. This phenomenon has its origin in the higher curvature term with $f(R)$ gravity in the bulk.

Vacuum state in the context of cosmology

It was recently found that gravity theory in four dimensions admits a new topological vacuum angle, similar to the theta angle of gauge theories. As a result, the quantum theory of gravity exhibits a non-perturbative vacuum structure. Here **Sandipan Sengupta** studies the implication of this new vacuum state in the the context of cosmology and proposes a framework, which can provide a solution to the cosmological constant problem.

Finite temperature effects and quantum gravity

Sandipan Sengupta and collaborators find a class of metrics in gravity theory, which can interpolate between metrics corresponding to an inertial observer and an accelerated observer. They provide an instantonic interpretation of these configurations and demonstrate that these are related to the existence of 'large' diffeomorphisms in gravity theory. Further investigations regarding their relevance in the quantum theory of gravity is in progress.

Cosmology and Structure Formation

Emergent cosmology

The inflationary scenario has proved to be successful in describing a universe which is remarkably similar to the one which we inhabit. Yet, despite its very impressive achievements, the inflationary paradigm leaves some questions unanswered. These pertain both to the nature of the inflaton field and to the state of the universe prior to the commencement of inflation. It is well known that inflation (within a general relativistic setting) could not have been past eternal. The question, therefore, arises of whether the universe could have existed 'eternally' in a quasi-static state, prior to inflation.

Satadru Bag, Yuri Shtanov, Sanil Unnikrishnan and **Varun Sahni** have explored the possibility of emergent cosmology using the *effective potential* formalism. The (00) Einstein equation can be recast in terms of the effective potential $U(a)$ as follows: $\frac{1}{2}\dot{a}^2 + U(a) = E \equiv -\frac{k}{2}$, where $U(a) = -\frac{\kappa}{6}a^2\sum_{i=1}^{2}\rho_i$.

The Einstein Static Universe (ESU) arises when the following conditions are simultaneously satisfied: $\dot{a} = 0, \ddot{a} = 0$.

They have discovered new models of emergent cosmology, which satisfy the constraints posed by the cosmic microwave background (CMB). They have demonstrated that within the framework of modified gravity, the emergent scenario can arise in a universe which is spatially flat/open/closed. By contrast, within the framework of general relativity, emergent cosmology arises from a (spatially closed) past-eternal ESU. In this case, the ESU is unstable (see Figure 4), which creates fine tuning problems for emergent cosmology. However, modified gravity models including Braneworld models, Loop Quantum Cosmology (LQC) and Asymptotically Free Gravity result in a stable ESU (see Figure 5). Consequently, in these models emergent cosmology arises from a larger class of initial conditions, including those in which the universe eternally oscillates about the

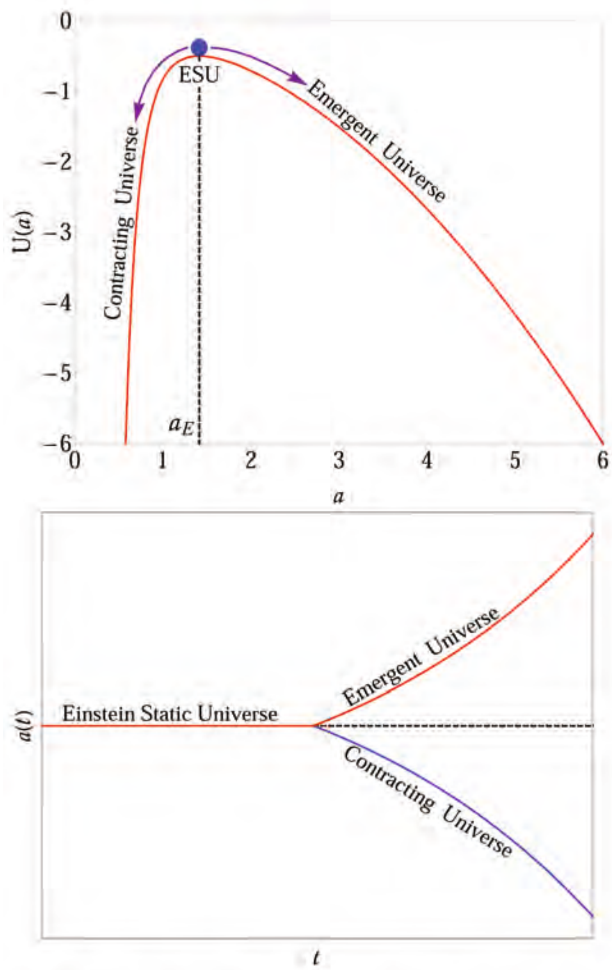


Figure 4: The effective potential (top panel) is schematically shown for a universe consisting of two components, one of which satisfies the strong energy condition $\rho + 3P \geq 0$, while the other violates it. The maxima of the effective potential corresponds to the ESU for which the expansion factor is a constant. However, ESU is unstable to small perturbations and can, therefore, be perturbed either into an accelerating emergent cosmology, or into a contracting singular universe (below panel).

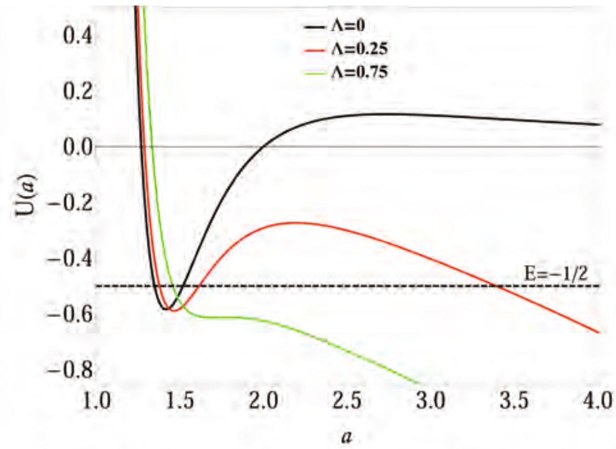


Figure 5: The effective potential for LQC is plotted for *some* values of Λ, where one assumes that the universe consists of stiff matter in addition to the cosmological constant. This combination mimics the behaviour of a scalar field rolling along a *flat* direction in the potential ($V' = 0$).

ESU fixed point. They have also demonstrated that such an oscillating universe is necessarily accompanied by particle production. For a large region in parameter space, particle production is enhanced through a parametric resonance, casting serious doubts as to whether in this case, the emergent scenario can be past-eternal. However, emergent models also exist which circumvent this difficulty.

Model independent evidence for dark energy evolution from baryon acoustic oscillations

Baryon Acoustic Oscillations (BAO) allow us to determine the expansion history of the Universe, thereby shedding light on the nature of dark energy. Recent observations of BAO's in the SDSS DR9 and DR11 have provided us with statistically independent measurements of $H(z)$ at redshifts of 0.57 and 2.34, respectively. **Varun Sahni**, Arman Shafieloo and A. Starobinsky have shown that these measurements can be used to test the cosmological constant hypothesis in a model independent manner by means of *an improved version of the Om diagnostic.* Their results

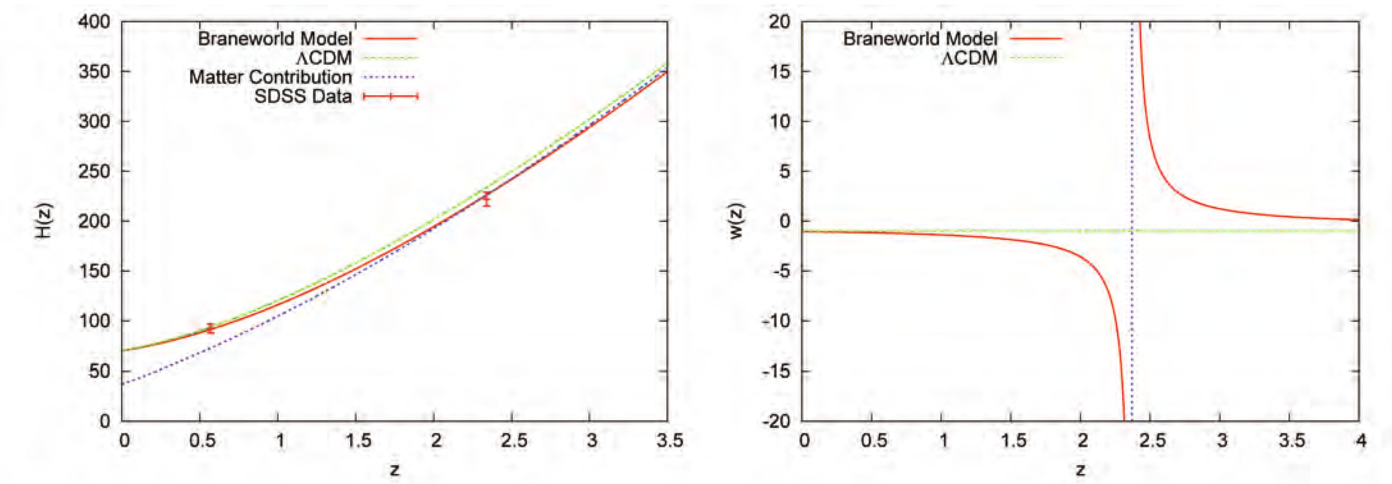


Figure 6: The Hubble parameter (left panel) and the effective equation of state of dark energy (right panel) are shown for the braneworld model of **Sahni** and Shtanov (solid red) and ΛCDM (dotted green). Also shown is the matter contribution: $H_0\sqrt{\Omega_{0m}(1+z)^3}$ where $H_0 = 70$ km/sec/Mpc and $\Omega_m = 0.28$ (dotted blue). In the braneworld model, the cosmological constant is *screened* in the past as a result of which the expansion rate drops *below* that in ΛCDM at high z. This feature permits the braneworld to better account for the low value of $H(z = 2.34)$ discovered by Delubac et al (2014). The associated pole in $w(z)$ at $z \simeq 2.4$ is shown in the right panel.

indicate that the recent SDSS DR11 measurement of $H(z) = 222 \pm 7$ km/sec/Mpc at $z = 2.34$, when taken in tandem with measurements of $H(z)$ at lower redshifts, imply considerable tension with the standard ΛCDM model. Their estimation of the new diagnostic Omh^2 from SDSS DR9 and DR11 data, namely $Omh^2 \approx 0.122 \pm 0.01$, which is equivalent to $\Omega_{0m}h^2$ for the spatially flat ΛCDM model, is in tension with the value $\Omega_{0m}h^2 = 0.1426 \pm 0.0025$ determined for ΛCDM from Planck+WP. This tension is alleviated in models in which the cosmological constant was dynamically *screened* (compensated) in the past. An example of such a model is the braneworld model of **Sahni** and Y. Shtanov (2003), in which the equation of state of dark energy has 'phantom' behaviour: $w_0 < -1$. Such screened dark energy models display a pole in the effective equation of state of dark energy at high redshifts, (see Figure 6) which emerges as a *smoking gun* test for these theories.

Mock galaxy catalogues showing galactic conformity

Aseem Paranjape, Katarina Kovac (ETHZ), William G. Hartley (ETHZ) and **Isha Pahwa** have developed an algorithm (extending previous work by others) to use N-body simulations of dark matter in order to generate galaxy properties such as positions, velocities, luminosities, colours and stellar masses, which match observations from the Sloan Digital Sky Survey. Galaxies in the catalogues are classified as central galaxies, which occupy the minima of gravitational potential wells and satellites which orbit around the centrals. A novelty in these catalogues is that they exhibit galactic conformity, in which star-forming satellite galaxies preferentially occupy groups whose central galaxies are also star-forming. The catalogues will be useful in devising new tests of various hypotheses concerning galaxy evolution and its connection with the assembly history of dark matter halos.

Observational Cosmology and Extragalactic Astronomy

Spiral galaxies as progenitors for pseudobulge hosting S0s

Bulges in galaxies can be defined as an excess of light towards the central region of the galaxy, which cannot be explained by inward extrapolation of the exponential profile obeyed by the light from the outer disk. These bulges come in two broad flavours: classical and pseudo. Classical bulges are dynamically hot, comprise of an older population of stars and have likely formed through merger driven processes. Pseudobulges, on the other hand are rotationally supported and have likely formed through secular processes taking place within the disk. Using imaging data at 3.6 micron obtained using the Spitzer Space Telescope, **Kaustubh Vaghmare**, Sudhanshu Barway and **Ajit Kembhavi** (2013) have derived structural parameters for an RC3 based sample of 185 S0 galaxies and used these to identify the pseudobulges. They have found that the disk scale lengths of pseudobulge hosts are on average smaller than those of their classical bulge hosting counterparts. This has been interpreted by them as a signature of the processes responsible for bulge growth.

An alternate explanation is that this is a signature of the processes that are responsible for transforming spirals into S0s. These processes such as ram pressure stripping and galaxy harassment can cause spiral arms to fade resulting in a spiral galaxy transforming into an S0. To verify this, **Vaghmare**, Barway, S. Mathur and **Kembhavi** (2015) have compared the 25 pseudubulge hosts of the RC3 sample of S0 galaxies with the 27 pseudobulge hosting spirals found in a sample used by Ghosh et al (2008) in study of nuclear X-ray emissions. They have found that the disk scale lengths of pseudobulge hosting S0s are smaller on average than those of the pseudobulge hosting spirals and interpreted the lowered disk scale length as luminosity caused by fading of spiral arms. By comparing the bulge luminosities, they have also showed that early type spirals were the more likely progenitors of S0 galaxies in this scenario.

Star formation history of S0 galaxies with SALT

Recent observational studies done by Sudhanshu Barway et al. (2007, 2009, 2011, 2013) and **Kaustubh Vaghmare** et al. (2013, 2015) have demonstrated that as a class, S0 galaxies are quite complicated with several sub-populations with vastly different formation histories. The dominant formation mechanism has been shown to be a function of the luminosity with the environment contributing as well. All these studies have been done using photometric analysis for samples comprising statistically meaningful number of galaxies. However, to accurately construct the star formation histories of these galaxies, one needs to obtain spectroscopic data and use the technique of stellar population synthesis. This is the goal of an ongoing study being done by **Vaghmare**, Barway, Petri and **Ajit Kembhavi** using longslit data obtained through Robert Stoby Spectropgraph (RSS) on the Southern African Large Telescope (SALT).

The study involves detailed data reductions to account for several instrumental signatures and extracting spectra using an inverse flux-weighed scheme along the longslit. Each spectrum, corresponding to a position along the major axis of the galaxy is modelled as a linear combination of simple stellar populations (SSPs) obtained by the MILES project. The modelling is done by Starlight, a tool developed by Cid Fernandes et al. The tool models the input spectrum as a linear combination of various components, known as a base. To obtain a better coverage of the parameter space, techniques such as difffusion mapping and K-means clustering are used. A pipeline has been developed to perform all the analyses, and preliminary results have been obtained.

Astronomy of transients

The information of the true photometric variability of a source is not straightforward to obtain using realistic data. In the ideal scenario where one has infinite data points with zero measurement errors, the process of judging whether an astronomical source is variable or not is simple. However, in realistic cases, any method of estimating variability has to struggle with distinguishing between noise and the actual variability of the source. A single estimate of the actual variability is not sufficient. We need to have information about how confident we are of the estimated measurement. In other words, we need a probability distribution of the true variability. A semi-analytical technique to obtain the same has been developed and tested by **Kaustubh Vaghmare**, **Aditya Rotti**, **Varun Bhalerao**, Pawar and Bellm. This technique is applicable for stochastically varying Gaussian sources.

The technique involves the method of characteristic functions to derive the probability distribution of the variance of a source given the noise information of the photometric measurements. By deriving these distributions for different actual variabilities, one can obtain the distribution of actual variability for the given source. The technique has been tested using blind studies involving synthetic data simulated using realistic photometric uncertainties from the Palomar Transient Factory (PTF) as well as real data. The development of this study is a part of a larger project aimed at developing a statistical machinery to search for optical counterparts for X-ray sources in the ROSAT Bright Source Catalog using variability as one of the metrics.

ASTROSAT CZTI

CZTI *(Cadmium Zinc Telluride Imager)* is one of the instruments on board the upcoming ASTROSAT satellite, to be launched before the end of this year. The instrument is being assembled by A. R. Rao's group at TIFR, Mumbai. Calibration data acquired at TIFR is reduced and analysed at IUCAA, as per a memorandum of understanding between the two institutes. IUCAA members active in this phase of instrument development are **Dipankar Bhattacharya, Gulab Dewangan, Nilkanth Vagshette**, **Ajay**

Vibhute, Pramod Pawar (visiting student) and **Varun Bhalerao**.

Bhalerao has continued his involvement in the ground calibration of CZTI, as well as extension to in–flight updates of this calibration. We have made detailed plans for cross–calibration with other satellites once ASTROSAT is launched. We have also defined algorithms for in–flight health monitoring, detecting and handling noisy or flickering pixels, etc. Finally, we have defined algorithms for detecting transients in the wide field of view of CZTI, and are working on policies to analyse/report such transients.

Extensive simulations have been carried out to assess the capability of the ASTROSAT CZTI in the detection of X-ray polarisation. The results indicate that events in the energy range of 100 keV to 250 keV, where the 5 mm thick CZT detector has significant detection efficiency, can be used for polarimetric studies. A minimum detectable polarisation (MDP) at the level of $\sim$10% can be achieved for bright Crab like X-ray sources with exposure time of $\sim$500 ks. Preliminary experiments have been carried out to verify the results from these simulations. This work has been done by **Bhattacharya** and **Prasant Bera** in collaboration with Tanmoy Chattopadhyay (PRL) with other members of the ASTROSAT CZTI team.

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

It is now well recognized that active galactic nuclei (AGNs) play a vital role in the formation and evolution of their host galaxies. While various observational results confirm that the AGN feedback strongly influences the evolution of its host galaxy and the environment, the conditions prevailing in the host galaxy may also quench or trigger the AGN activity by altering the rate of accretion on to the central supermassive black hole. One of the important questions in our understanding of the AGN is what triggers the AGN activity? The galaxy-galaxy mergers represent one of the natural mechanisms to funnel large quantities of gas to the central (<1 pc) regions of galaxies and trigger the AGN. Therefore, a natural way to test the connection between galaxy-galaxy mergers and the triggering of AGN activity will be to observe the properties of circumnuclear gas in AGN hosts associated with mergers.

R. Srianand, **Neeraj Gupta** and their collaborators (E. Momjian and **M. Vivek**), using long-slit optical spectra obtained with the 2 m telescope at IUCAA Girawali Observatory, show that the radio source J094221.98+062335.2 (z = 0.123) is associated with a galaxy pair undergoing a major merger. Its companion (Object-B in the image) is a normal star-forming galaxy infalling with a velocity of 185 km/s at a projected separation of 4.8 kpc. Using the Westerbork Synthesis Radio Telescope (WSRT) in Netherlands and Giant Metrewave Radio Telescope (GMRT) in India, they have detected a strong HI 21 cm absorption at the systemic redshift of the radio galaxy with column density, N(HI)$\sim 9\times10^{21}$ cm^{-2} for an assumed spin temperature of 100 K. Such a strong HI 21 cm 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. **Srianand** et al. have shown that the strong 21 cm absorption is consistent with it being 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 lines probably represent cold HI gas falling into the radio source. The presence of high concentration of HI 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. Detailed study of a sample of merging galaxy pairs associated with bright radio sources to understand this issue is in progress.

UV cosmic origin spectrograph

With the help of a newly installed ultraviolet (UV) Cosmic Origin Spectrograph on board Hubble Space Telescope, recently, Danforth et al. (2014) studied the H I gas distribution at low redshift Universe through many quasar spectra. It turns out that to reproduce this H I distribution in a cosmological hydrodynamic simulations, the required UV background (UVB) radiation (here, quantified by H I photoionization rate or Γ_{HI}) is 2 to 5 times higher (Shull et al. (2015) and Kollmeier et al. (2014)) than a well-known theoretical estimate of it by Haardt and Madau (2012). The known sources of the UVB are quasars, and H I ionizing photons emitted from galaxies quantified by a parameter called as escape fraction f_{esc}. To get this very high Γ_{HI} in the above UVB model of HM while using same quasar and galaxy emissivity, one needs $f_{esc} = 15\%$ at $z = 0$, which is extremely high. It is because at low redshifts various observations suggest that the f_{esc} is not more that 5%. This apparent discrepancy has led to the claim of a 'photon underproduction crisis'. It suggests that the known sources of UV radiation may not be sufficient to generate the inferred Γ_{HI}, and the origin of more than 80% of this UV radiation is unknown and perhaps generated from non-standard sources like decaying dark matter particles. These claims generated a considerable interest in astronomy community and led us to investigate them by studying the actual contributions of quasars and galaxies to the UVB.

Vikram Khaire and **R. Srianand** (2013) have developed a numerical code to estimate the UV background in lines with Haardt and Madau (2012.) In this code, we update the quasar emissivity from the recent measurements of quasar luminosity functions and find that it is factor 2 higher than what is used by HM. It directly gives 2 times higher Γ_{HI} (see Figure 7). From our previous work on star formation history (**Khaire** and **Srianand** (2015)) we know that the galaxy emissivity is factor 3 higher than what is used by Haardt and Madau. Using these in our UVB code to get the 5 times Γ_{HI}, we need $f_{esc} = 4\%$ (see Figure 7). Therefore, we conclude that the crisis is not as severe as it was perceived before and there seems no need to look for alternate explanations such as decaying dark matter particles. The known galaxies and quasars can easily produce it.

White dwarfs

Dipankar Bhattacharya and **Prasant Bera** have investigated the structure and mass-radius relation of strongly magnetised white dwarfs. The result of equilibrium calculations show that the upper mass limit of white dwarfs can be extended by nearly 0.5 solar mass in the presence of strong poloidal magnetic fields. Such super-Chandrasekhar mass white dwarfs may be responsible for ultra-luminous Type Ia supernovae. This research also shows that the role played by Landau quantization of electron orbits in strong magnetic field does not have any significant impact on the structure of the white dwarf or its limiting mass.

Archival data of the Rossi X-ray Timing Explorer has been analysed to study the properties of narrow quasi-periodic oscillation (QPO) features observed in the X-ray power spectrum of accreting stellar mass black hole sources. It has been found that while the fundamental and the first harmonic oscillations display features of frequency modulation, an additional amplitude modulated sub-harmonic feature also appears to be present. This work has been done in collaboration with Devraj Pawar (University of Mumbai) and researchers from Brera Observatory, Milan.

A gamma-ray flare of the blazar PKS1222+216 has been studied using extensive multi-wavelength data from FERMI-LAT and SWIFT satellites and the ground-based MAGIC telescope. The evolution of the spectral energy distribution during the flare was modelled as that arising from recollimation and subsequent deceleration of the blazar jet. This work has been done by **Bhattacharya** and **Bera** in collaboration with Pankaj Kushwaha (TIFR) and other members of the Indian Blazar modelling group.

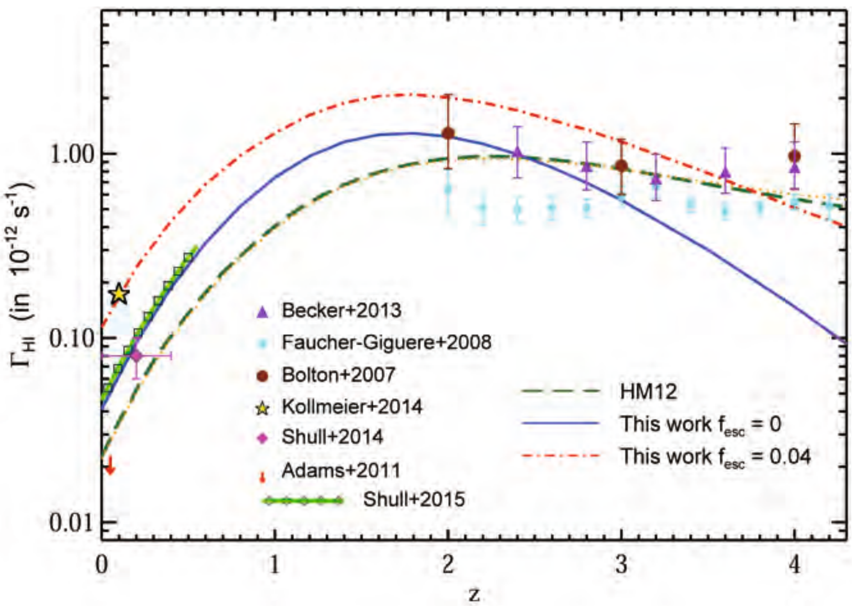


Figure 7: The $\Gamma_{\rm HI}$ vs redshift (z) obtained for UVB with updated quasar emissivity and galaxy contribution with $f_{\rm esc} = 0$ (*solid curve*) and with $f_{\rm esc} = 4\%$ (*dot-dash curve*) along with the $\Gamma_{\rm HI}$ from Haardt and Madau (2012) (*dash curve*) are plotted. The $\Gamma_{\rm HI}$ measurements at different redshifts from literature are shown. The inferred $\Gamma_{\rm HI}$ at low redshifts which led to the claim of photon underproduction crisis by Kollmeier et al (2014) (*star*) and Shull et al (2015) (*green curve with diamonds*) are also plotted. Our curves passing through these points clearly show that the known galaxies and quasars can easily resolve the photon underproduction crisis.

The X-ray (*Chandra* archive)

The X-ray (*Chandra* archive) and radio (*GMRT*) observations of ZWcl 2701 by **Nilkanth Vagshette** show an extensive pair of X-ray cavity (or bubble) in East and West direction within a central region of cluster ($<$ 20 kpc) along with bright rims around the cavity, suggest that radio lobes have displaced the X-ray emitting hot gas that compresses into a shell that appears bright rim like structure. The detected X-ray cavities allow us to measure the cavity power (or mechanical power) directly, which heats up the surrounding gas. Comparison between mechanical power ($\sim 5.96 \times 10^{44}$ erg s^{-1}) and cooling luminosity ($3.5 \times 10^{44} erg\, s^{-1}$) within the cooling radius (105 kpc) suggest that the mechanical power of AGN outburst is large enough to balance the radiative cooling in the system. The star formation rate measured from Hα luminosity is found to be ~ 0.60 $M_{\odot} yr^{-1}$, which is much less than the cooling rate ~ 196 $M_{\odot} yr^{-1}$, shows the existence of cooling flow problem. The floor entropy in the cool core cluster galaxy ZWcl 2701 indicates that the presence of alternative heating in the centre may be from AGN feedback mechanism. The X-ray temperature and metal abundance profile clearly reveal the existence of cooling flow in this ZWcl 2701 cluster.

Apart from this, **Vagshette** has been involved in the calibration of ASTROSAT CZTI detector. We have evaluated the dead, noisy and bad pixels on the basis of photometric and spectroscopic method. Using X-ray spectroscopic calibration data obtained by shining four radioactive source on each quadrant at $05 - 20°C$ temperature, we calculate the pixel wise gainoffset, and test the temperature and energy dependence properties such as resolution, sigma, etc.

Global instability studies of superthin galactic disk

Some low surface brightness galaxies are known to have extremely thin stellar disks with the vertical to planar axes ratio 0.1 or less, often referred to as superthin disks. Also, these galaxies are bulgeless, i.e., devoid of a central spheroidal component, called the bulge, which is a characteristic feature of most disk galaxies in general. Earlier studies of **Arunima Banerjee** have shown that it is the compact dark matter halo which plays the decisive role in determining the superthin disk distribution in low-mass disks. Recent studies have indicated that the dark matter halo is also responsible in inhibiting the growth of axisymmetric/non-axisymmetric local instabilities in these superthin disks. It is shown that although the disk is stable to local perturbations, it is unstable to the growth of global non-axisymmetric perturbations, which are responsible for the growth of bars and spiral arms in a galactic disk.

A tilted dark matter halo: Signatures on disk structure and dynamics

The cold, neutral hydrogen (HI) component of the galactic disk serves as a valuable tracer of the shape and density profile of the dark matter halo in a nearby edge-on disk galaxy. This is because the size of the HI disk is about 3 - 4 times that of the stellar disk and therefore, HI effectively responds to the underlying gravitational potential of the dark matter halo only in the outer galaxy. The dark matter halo is conventionally modelled to be oblate or prolate in shape with its symmetry axis aligned with that of the galactic disk. However, the recent N-body simulation studies of galaxies have indicated that the symmetry axis of the galactic disk may lie off the principal planes of the dark matter halo. In this project, **Arunima Banerjee** and Chanda J. Jog have modelled the outer galactic HI disk responding as test particles to the dark matter halo potential, the latter being either prolate or oblate in shape and also tilted with respect to the disk symmetry axis. The effect of a tilted dark matter halo on the observed HI rotation curve and the HI vertical scale height curves of the galaxy are also investigated.

Modelling the structure and kinematics of the interacting galaxy U5189 using IDENTIKIT

Arunima Banerjee, Jayaram Chengalur et al. have obtained a dynamical model of the interacting system U5189 using HI 21 cm radio observations as the tracer. The parameter space of the encounters is constrained using the IDENTIKIT model-matching and visualization tool. IDENTIKIT utilizes hybrid N-body and test particle simulations to enable rapid exploration of the parameter space of galaxy mergers. The IDENTIKIT - derived matches of these systems are reproduced with self-consistent collisionless simulations, which show very similar results. The models generally reproduce the observed morphology and HI kinematics of the tidal tails in these systems with reasonable properties inferred for the progenitor galaxies.

Cosmic Magnetic Fields

Fluctuation dynamo at finite correlation times using renewing flows

Fluctuation dynamos are generic to turbulent astrophysical systems. The only analytical model of the fluctuation dynamo, due to Kazantsev, assumes the velocity to be delta-correlated in time. This assumption breaks down for any realistic turbulent flow. **Pallavi Bhat** and **Kandaswamy Subramanian** have generalized the analytic model of fluctuation dynamo to include the effects of a finite correlation time, τ, using renewing flows. The generalized evolution equation for the longitudinal correlation function M_L leads to the standard Kazantsev equation in the $\tau \to 0$ limit, and extends it to the next order in τ. We have found 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 the Landau-Lifschitz approach, to one with at most second derivatives of M_L. Using both a scaling solution and the WKBJ approximation, we have shown 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.

Saturation of Zeldovich stretch-twist-fold map dynamos

Zeldovich's stretch-twist-fold (STF) dynamo provided a breakthrough in conceptual understanding of fast dynamos, including the small scale fluctuation dynamos. Amit Seta, **Pallavi Bhat** and **Kandaswamy Subramanian** have studied 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. Such maps allow 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. Incorporating a diffusive step parameterised by R_m into the map, we find that the magnetic field $B(x)$ is amplified only above a critical $R_m = R_{crit} \sim 4$ for both types of dynamos. 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 $R_m = R_{sat}$, 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 fluctuation dynamos.

Traces of large-scale dynamo action in the kinematic stage

Using direct numerical simulations (DNS), **Kandaswamy Subramanian** and Axel Brandenburg have verified that in the kinematic regime, a turbulent helical dynamo grows in such a way that the magnetic energy spectrum remains to high precision shape-invariant, i.e., at each wavenumber k, the spectrum grows with the same growth rate. Signatures of large-scale dynamo action can be identified through the excess of magnetic energy at small k one of the two oppositely polarized constituents. Also a suitably defined planar average of the magnetic field can be chosen such that its rms value isolates the strength of the mean field. However, these different means of analysis suggest that the strength of the large scale field diminishes with increasing magnetic Reynolds number R_m, like $R_m^{-1/2}$ for intermediate values and like $R_m^{-3/4}$ for larger ones. An analysis from the Kazantsev model, including helicity and the DNS, show that this arises due to the magnetic energy spectrum still peaking at resistive scales, even when helicity is present. As expected, the amplitude of the large scale field increases with increasing fractional helicity, enabling us to determine the onset of large scale dynamo action and distinguishing it from that of the small scale dynamo. Our DNS show that, contrary to earlier results for smaller scale separation (only 1.5 instead of now 4), the small scale dynamo can still be excited at magnetic Prandtl numbers of 0.1 and only moderate values of the magnetic Reynolds numbers (~ 160).

Magnetic spiral arms and galactic outflows

Galactic magnetic arms have been observed between the gaseous arms of some spiral galaxies; their origin remains unclear. **Luke Chamandy**, Anvar Shukurov and **Kandaswamy Subramanian** have suggested that magnetic spiral arms can be naturally generated in the interarm regions, because the galactic fountain flow or wind is likely to be weaker there than in the arms. Galactic outflows lead to two countervailing effects: removal of small scale magnetic helicity, which helps to avert catastrophic quenching of the dynamo, and advection of the large scale magnetic field, which suppresses dynamo action. For realistic galactic parameters, the net consequence of outflows being stronger in the gaseous arms, is higher saturation large-scale field strengths in the interarm regions as compared to in the arms. By incorporating rather realistic models of spiral structure and evolution into our dynamo models, an interlaced pattern of magnetic and gaseous arms can be produced.

Helical cosmological magnetic fields from extra-dimensions

Kandaswamy Subramanian and collaborators study the inflationary generation of helical cosmological magnetic fields in a higher dimensional generalization of the electromagnetic theory. For this purpose, we also include a parity breaking piece to the electromagnetic action. The evolution of extra dimensional scale factor allows the breaking of conformal invariance of the effective electromagnetic action in $1+3$ dimensions required for such generation. Analytical solutions for the vector potential can be obtained in terms of Coulomb wave-functions for some special cases. We also present numerical solutions for the vector potential evolution in more general cases. In the presence of a higher-dimensional cosmological constant, there exist solutions for the scale factors in which both normal and extra dimensional space either inflate or deflate simultaneously with the same rate. In such a scenario, with the number of extra dimensions $D = 4$, a scale invariant spectrum of helical magnetic field is obtained. The net helicity arises, as one helical mode comes to dominate over the other at the super-horizon scales. A magnetic field strength of the order of 10^{-9} G can be obtained for the inflationary scale $H \simeq 10^{-3}$ M_{pl}. Weaker fields will be generated for lower scales of inflation. Magnetic fields generated in this model respects the bounds on magnetic fields by Planck and γ-ray observations (i.e., 10^{-16} $G < B_{obs} < 3.4 \times 10^{-9}$ G).

Gravitational Waves

Observational constraints on spinning, relativistic Bose-Einstein condensate stars

Bose-Einstein condensates (BECs) have been proposed as candidate states of matter for the interior of neutron stars. Specifically, Chavanis and Harko obtained the mass-radius relation for a BEC star and proposed that the recently discovered neutron stars with masses around $2M\odot$ are BEC stars. They employed a barotropic equation of state (EOS), with one free parameter, that was first found by Colpi, Shapiro and Wasserman (CSW), to describe them and derive stable equilibrium configurations of spinning BEC stars in general relativity. In this work, **Sukanta Bose** collaborated with Shreya Shah (Gujarat University) and Arunava Mukherjee (TIFR, Mumbai) to show that while it was true that BECs allow for compact object masses as heavy as the heaviest observed ones. Such stars cannot simultaneously have radii that are small enough to be consistent with the latest observations, in spite of the flexibility available in the EOS in the form of the free parameter. In fact, their conclusion applies to any spinning relativistic Boson star that obeys the CSW EOS. Therefore, any matter that obeys the CSW EOS is practically ruled out as the constituent of neutron stars observed in nature. Note that this conclusion does not preclude (a) Boson stars obeying a different EOS, in general, or neutron stars with an interior composition of BECs of kaons or pions obeying a different EOS, in particular; (b) Boson stars obeying the CSW EOS but with masses that are very different, e.g., comparable to supermassive black hole masses. In the latter case, however, one is still left with the problem of explaining why stellar mass objects are not favoured while much heavier objects of the same EOS are allowed.

Improved upper limits on the stochastic gravitational-wave background from 2009 - 2010 LIGO and Virgo data from a variety of sources are predicted to superpose to create a stochastic background. This background is expected to contain unique information from throughout the history of the Universe that is unavailable through standard electromagnetic observations, making its study of fundamental importance to understand the evolution of the Universe. **Bose** and his former student Dipongkar Talukder (now at University of Oregon) contributed to this study of the LIGO Scientific and Virgo Collaborations, which carried out a search for the stochastic background with the latest data from the LIGO and Virgo detectors. Consistent with predictions from most stochastic gravitational-wave background models, the data display no evidence of a stochastic gravitational-wave signal. We discuss the implications of these results in light of the recent claim by the BICEP2 experiment of the possible evidence for inflationary gravitational waves.

The NINJA-2 project

The Numerical INJection Analysis (NINJA) project is a collaborative effort between members of the numerical relativity and gravitational-wave (GW) astrophysics communities. The purpose of NINJA is to study the ability to detect GWs emitted from merging binary black holes (BBH) and recover their parameters with next-generation GW observatories. **Sukanta Bose** and his former student Thilina Dayanga contributed to this study, which reports on the results of the second NINJA project, NINJA-2, which employs 60 complete

BBH hybrid waveforms consisting of a numerical portion modelling the late inspiral, merger, and ringdown stitched to a post-Newtonian portion modelling the early inspiral. In a 'blind injection challenge' similar to that conducted in recent Laser Interferometer Gravitational Wave Observatory (LIGO) and Virgo science runs, we added seven hybrid waveforms to two months of data re-coloured to predictions of Advanced LIGO (aLIGO) and Advanced Virgo (AdV) sensitivity curves during their first observing runs. The resulting data was analysed by GW detection algorithms, and six of the waveforms were recovered with false alarm rates smaller than one in a thousand years. We have found that the strong degeneracy between the mass ratio and the BHs' angular momenta will make it difficult to precisely estimate these parameters with aLIGO and AdV. We also have performed a large scale Monte Carlo study to assess the ability to recover each of the 60 hybrid waveforms with early aLIGO and AdV sensitivity curves. Our results predict that early aLIGO and AdV will have a volume-weighted average sensitive distance of 300 Mpc (1 Gpc) for $10M_{\odot} + 10M_{\odot}(50M_{\odot} + 50M_{\odot})$ BBH coalescences. We have demonstrated that neglecting the component angular momenta in the waveform models used in matched-filtering will result in a reduction in sensitivity for systems with large component angular momenta. This reduction is estimated to be up to 15% for $50M_{\odot} + 50M_{\odot} BBH$ coalescences with almost maximal angular momenta aligned with the orbit using early aLIGO and AdV sensitivity curves.

Stochastic gravitational-wave background from exoplanets

The Kepler mission has detected an enormous number of extrasolar planets, which has lead to orders of magnitude increase in the expected number of exoplanets as compared to the earlier expectations. **Anirban Ain** and **Sanjit Mitra**, along with a student, Shilpa Kastha from Visva-Bharati University, have estimated the stochastic GW background created by the expected distribution of planets in our galaxy. They have found that this background is far below the sensitivity of Pulsar Timing Arrays (PTA), even with the Square Kilometre Array (SKA). However, the peak of the background spectrum is not so far below the design sensitivity of proposed spaced based GW missions. A future space based mission may be able to observe or tightly constrain this signal, which will possibly be the only way to probe the galactic population of exoplanets as a whole (see Figure 8).

Folding data for fast gravitational wave radiometry

Collection of distant and unresolved astrophysical sources of gravitational waves (GW) and certain early universe phenomena are expected to create stochastic backgrounds, containing information about the origin and the content of the universe, not accessible to traditional electro-magnetic astronomy. GW radiometry is an optimal method to probe such a background, where data from pairs of detectors are correlated with appropriate time and direction dependent phase delays. **Anirban Ain** and **Sanjit Mitra**, along with Prathamesh Dalvi, a student from BITS-Pilani, Goa Campus, have developed a novel technique to fold Cross Spectral Density of data from a pair of GW detectors for the whole observation time (few years) to only one sidereal day's data. This reduces computation cost for radiometer analysis by about three orders of magnitude and dramatically improves handling and portability of data. They have implemented this method on real LIGO data and showed that the results obtained from unfolded LIGO data and the same obtained from the folded data match within ~ 0.01

Folded data will enable important searches that would not have been possible earlier mainly due to computational challenges. **Mitra, Ain** and their collaborators have proposed a blind all sky search for narrowband sources, e.g., for unknown milli-second pulsars, using folded data (See Figure 9).

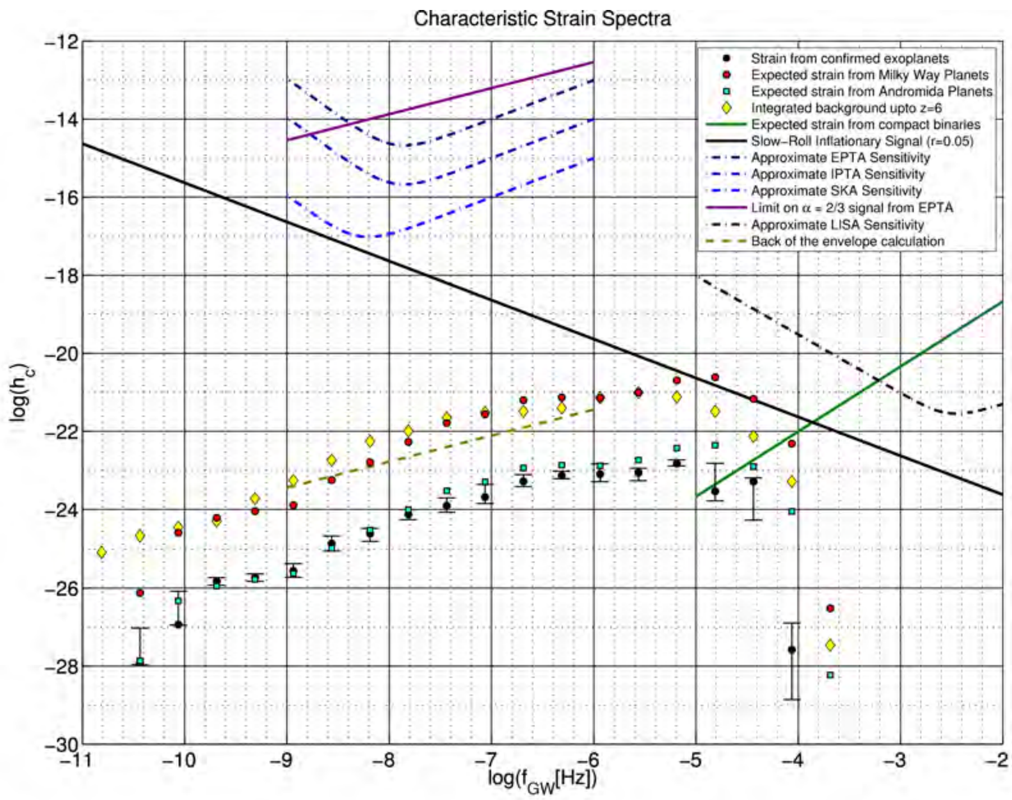


Figure 8: Estimates of characteristic strain of stochastic background created by exoplanets from Milky Way, Andromeda Galaxy and the whole universe (LCDM cosmology, integrating upto redshift z=6) are shown here. The sensitivities of the proposed space based gravitational wave observatory LISA and current and proposed Pulsar Timing Arrays (PTA), and their current 95% confidence upper limit for a spectral index of 2/3 are also overlaid here to shed light on the detectability of the background. In the higher frequencies, the background is not too far below the LISAs proposed sensitivity curve, which may give one hope that one day a future space based GW mission will be able to probe this background.

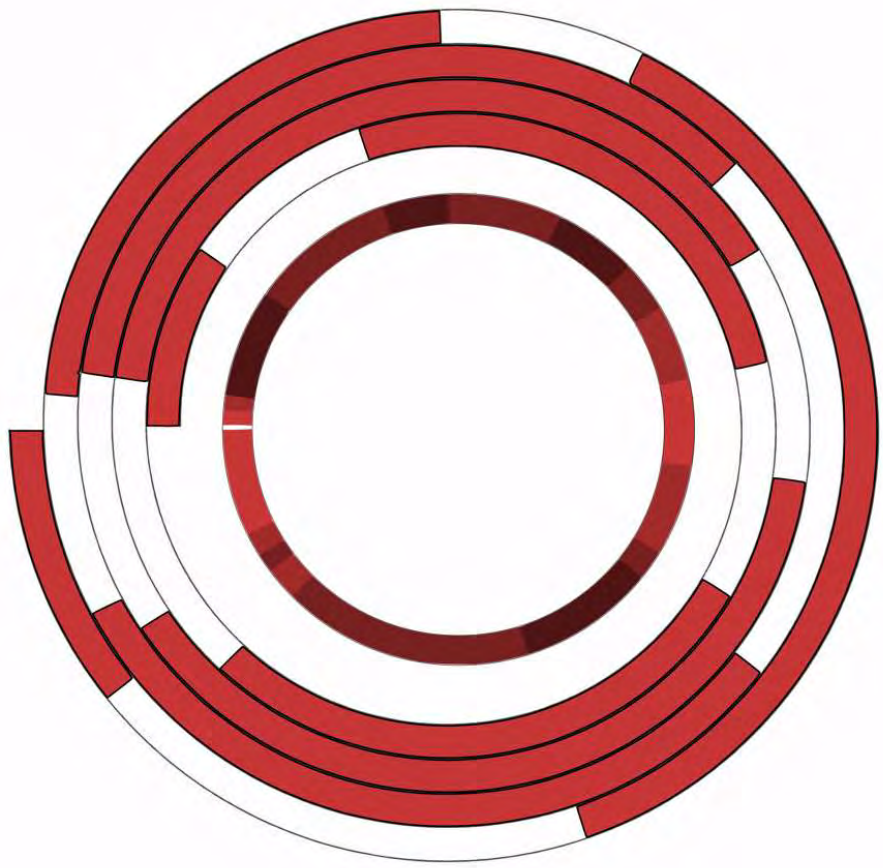


Figure 9: This is an illustration of the folding algorithm. Time series data collected from gravitational wave detectors are represented by the spiral. Time increases along the spiral and proportional to the angle made by an arc at the centre, such that 360 degrees corresponds to one sidereal day, represented by the inner circle. If one drew imaginary spokes emanating from the centre of the circle, the sections of the spiral falling between two successive spokes have the same sidereal time, hence, they can be folded on to the section on the inner circle. Red colour represents availability of quality data and white represents otherwise. Darker the colour on the circle, more the data that were folded. Note that what is folded is cross power spectral data from a pair of detectors, not the data from individual detectors.

Electromagnetic followup of gravitational wave sources

Gravitational wave observatories like LIGO and Virgo are expected to detect the first gravitational waves (GW) in the next few years. For a complete astrophysical understanding of these sources, detection of counterparts at electromagnetic (EM) wavelengths is crucial. This is technically very challenging, as the field of view of typical optical telescopes is $\sim$ 0.1 deg^2, while the positional uncertainty for detected gravitational wave sources will be tens of deg^2. This requires careful planning, automation of telescopes, and upgrading facilities to have wide fields of view.

In this context, we have signed memoranda of understanding with the LIGO-Virgo collaboration, in order to receive information about any tentative gravitational wave detections that may be followed-up from India. **Varun Bhalerao** is currently collaborating with Shashikiran Ganesh, Anand Sengupta and Akash to automate PRL's 0.5 m telescope at Mt. Abu. Sujay Mate, Atharva Patil and Swanand Khanapurkar, project students from IISER Pune, have been working with **Sukanta Bose** and **Bhalerao** to create a local test system with IUCAA's 14" telescope for automated imaging of large parts of the sky. **Javed Rana** is working with **Bose** and **Bhalerao** to develop an optimal algorithm to plan a sequence of observations to tile a large area of the sky with a small-field-of-view telescope.

Bhalerao is also in touch with Padmakar Parihar and G. C. Anupama at IIA and Shashi Bhushan Pandey at ARIES for collaborating with their resources for such a follow-up.

Gravitational wave in quasi-steady state cosmology

Jayant V. Narlikar, in collaboration with **Sanjeev V. Dhurandhar**, R.G. Vishwakarma, S.R. Valluri and Sayantan Auddy have calculated the expected gravitational wave background in the Quasi-Steady State Cosmology (QSSC). The calculation was based on an assumed creation rate of matter in the form of explosive events happening closer to the minimum of each oscillation. A comparison could be made with the prediction of gravitational wave background expected from the inflationary cosmology.

Cosmic Microwave Background

The Universe as seen by Planck

European Space Agency's Planck Surveyor Mission announced its first full sky measurement of the CMB temperature anisotropy in April 2013. The measurements capture about ten times more information on the anisotropy as compared to the previous such mission, the Wilkinson Microwave Anisotropy Probe (WMAP). The results were published in the form of thirty one articles in a special issue of Astronomy and Astrophysics in October 2014. A team at IUCAA has made significant contribution to this effort. **Sanjit Mitra** has played a key role in accounting for systematic effects arising from asymmetric instrumental beams, which was crucial to ensure that the results not only have small error-bars, but also have high reliability. **Tarun Souradeep** has led a team at IUCAA comprising of **Pavan Aluri, Nidhi Pant, Aditya Rotti** and **Mitra**, to probe the violation of statistical isotropy of the universe. Statistical isotropy, one of the fundamental assumptions in standard cosmology, can now be tested, thanks to the high fidelity data from Planck. Apart from producing several important scientific results using the polarisation data, Planck and BICEP2/KECK collaborations have recently put the strongest upper limit so far on the amount of gravitational waves produced in the very early universe. This is a very important achievement, considering that the measurement is a direct probe of cosmic inflation (See Figure 10).

Effect of asymmetric instrumental beams on CMB parameter estimation

Measurement of the Cosmic Microwave Background (CMB) anisotropy plays a key role in precision cosmology. However, the

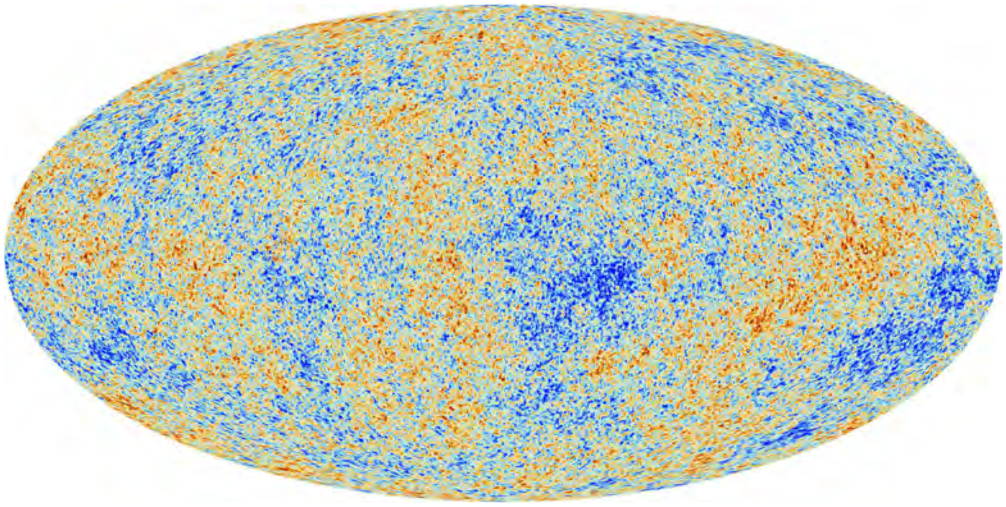


Figure 10: The temperature anisotropy map produced by European Space Agency's Planck Surveyor Mission using data from first 15.5 months of observation. [Credit: ESA]

precision can only be effective in practice if all the systematic effects have been accounted for with sufficient accuracy. Asymmetry of instrumental beams is perhaps the biggest source of systematic effect in CMB measurement. **Santanu Das** and **Sanjit Mitra,** along with a student, Sonu Tabitha Paulson from Madras University, have studied the effect of asymmetric beams, on cosmological parameter estimation. They have proposed a method based on the parameter estimation code ScoPE to accurately account for multipole-to-multipole coupling introduced by asymmetric beams. They have shown that the simulation based method followed by the Planck team can produce a very good estimate of the posterior distribution of the parameter, provided a two-step iterative scheme is followed (See Figure 11).

Statistical isotropy of the CMB sky

The Bipolar Spherical Harmonic (BipoSH) representation proposed a decade back has been steadily established by 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 the BipoSH spectra is a standard statistical technique to search for isotropy violations. This is a neat tool allowing a blind search for SI violations in the cosmic microwave background sky, as well as, hone in on the cause of isotropy violation by using appropriate combinations of BipoSH measures. **Tarun Souradeep** and his group has proposed a novel technique of constructing orthogonal BipoSH estimators, which can be used to discern between models of isotropy violation.

Pavan Aluri, Nidhi Pant, **Aditya Rotti** and **Souradeep** have developed a method to estimate signals of statistical anisotropy from a masked sky or a partial sky survey of CMB anisotropies. This has been employed in obtaining the Planck in isotropy and statistics in 2015. Plancks detector sensitivity allowed for the first time to estimate this velocity amplitude and direction independently using these correlations induced at all angular scales. A very important aspect in such analysis is to handle masks employed to block residuals in a clean CMB map. Masking introduces additional couplings bias in the recovery. However, this procedure is generic, and is also applicable to other types of signals of statistical anisotropy, such as the hemispherical power asymmetry in CMB at large angular scales, weak lensing, etc.

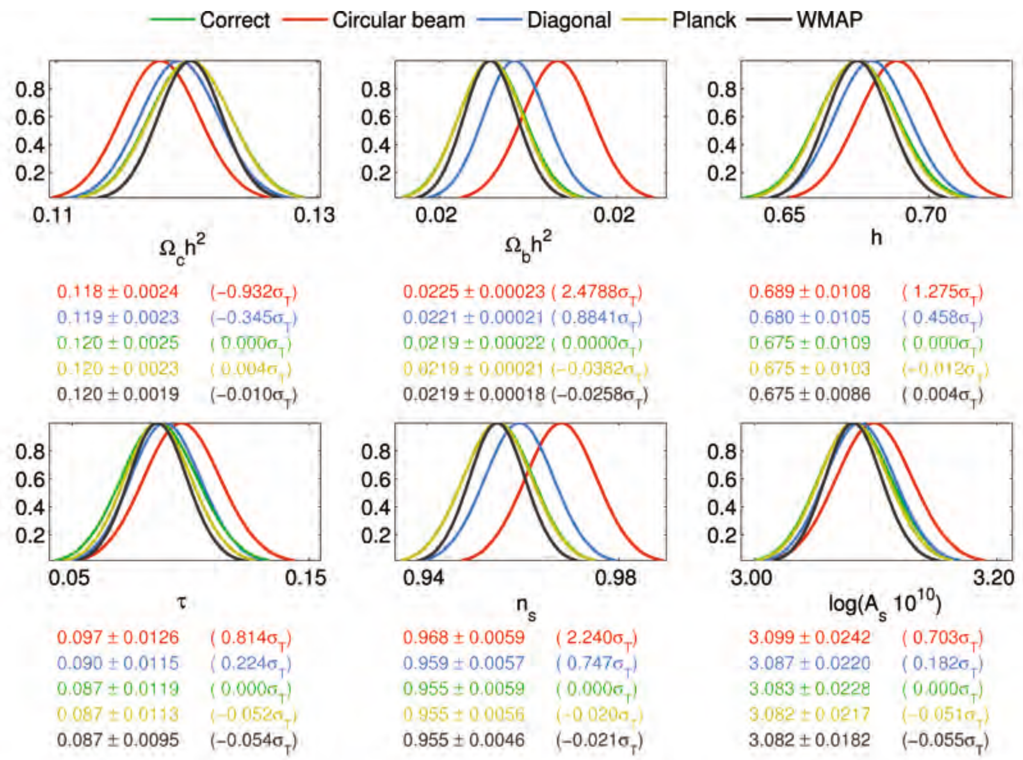


Figure 11: One dimensional marginal probability distributions for six cosmological parameters are shown here for different ways of handling of the instrumental beams. The "correct/true" distribution shows the results obtained by considering a general tensorial representation of the beam that we have incorporated in the parameter estimation code ScoPE. Since obtaining the exact tensorial representation of the beam is a daunting task in practice, we have shown how different approximate methods compare with the exact approach. Circular beam approximation and consideration of only the diagonal components of the beam tensor do not produce accurate results. However, a brute force scalar transfer function estimation starting from a fiducial power spectrum, which is not too different from reality, can provide satisfactory results. Here, we have shown how well the posterior distributions can be recovered from Planck data when the fiducial spectrum is the exact Planck best fit or a bit different WMAP best-fit.

Santanu Das and **Souradeep**, in collaboration with Ben Wandelt (Lagrange Institute, Paris) have taken on the challenge of estimating from CMB map BipoSH spectra jointly with angular power spectrum with their full posterior distribution. This ensures that entire information available is used in making the estimation. More importantly, it can reveal effects of the CMB power spectrum to SI violation. This challenge has involved in devising and implementing a novel method using Hamiltonian-Markov chain approach.

Non-parametric assertion of harmonicity in the Planck CMB spectra

In collaboration with Amir Aghamousa and Mihir Arjunwadkar (both from S.P. Pune University), **Tarun Souradeep** has pursued a programme of non-parametric approach to reveal cosmology from CMB data. In this line of work, together with Arman Shafieloo (APCTP, South Korea), they have recently established a comprehensive, non-parametric estimation of CMB power spectrum from Planck 2013 data. The non-parametric analysis resolves six peaks (and five dips) up to multipole of 1850 in the temperature angular power spectrum. They have also presented uncertainties in the peak/dip locations and heights at the 95% confidence level. It is further shown how these peak location reflect the harmonicity of acoustic peaks, and can be used for the estimation of the acoustic scale. Based on this non-parametric formalism, they have found the best-fit LCDM model to be at 36% confidence distance from the centre of the non-parametric confidence set. This is considerably larger than the confidence distance (9%) derived earlier from a similar analysis of the WMAP 7-year data. Another interesting result of the analysis is that at low multipoles, the Planck data do not suggest any upturn, contrary to the expectation based on the integrated Sachs-Wolfe contribution in the best-fit LCDM cosmology.

Early universe from CMB

In the past couple of year, with former IUCAA student Arman Shafieloo (APCTP, South Korea) and his post-doc Dhiraj Hazra, **Tarun Souradeep** has renewed the research programme on determining the Primordial Power Spectrum (PPS) from CMB data, and also assessing the impact on cosmological parameter estimation of allowing for a free form PPS. In a recent publication in JCAP, they have independently estimated the PPS from the Planck (2013), and found the reconstructed PPS from Planck temperature data, which can also substantially improve the fit to WMAP-9 angular power spectrum data (with respect to powerlaw form of the PPS) allowing an overall amplitude shift of 2.5%. Another important result of the analysis is the evidence of gravitational lensing through the reconstruction analysis. Finally, the team have presented two smooth form of the PPS containing only the important features. These smooth forms of PPS can provide significant improvements in fitting the data, and can be helpful to give hints for inflationary model building. The publication was reviewed by the Planck science team prior to submission and is listed as one of the early Planck external papers to be published.

Suvodip Mukherjee, **Santanu Das** and **Souradeep** in collaboration with IUCAA associate, Minu Joy have carried out a detailed study of the Perturbed Power Law (PPL) model of inflation, which is a soft deviation from power law (PL) inflationary model. This model captures the effect of higher order derivative of Hubble parameter during inflation, which in turn leads to a non-zero effective mass for the inflaton field.

The remarkable progress in CMB studies over the past decade has 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**, Asif Ahangar, a student of IUCAA associate Manzoor Malik (Kashmir University) and **Souradeep** have completed a comprehensive study of various models of inflation that have features at low multipoles in the context of the recent Planck (2013) data. The prominent common feature to all the models of PPS is an infra-red cut off, which leads to suppression of power at large angular scales. They have considered models of PPS with maximum of three extra parameters and use Akaike Information Criterion (AIC) as well as Bayesian Information Criterion (BIC) of model selection to compare the models. Inflationary models with cut off features lead to a mildy better fit of the observed data compared to simple power law model.

Efficient method of cosmological parameter estimation

Santanu Das and **Tarun Souradeep** have developed an adaptive Markov Chain Monte Carlo (MCMC) method that is significantly more efficient than the widely used MCMC sampler widely used for cosmological parameter estimation from CMB and other data. Due to the intrinsic serial nature of the MCMC sampler, convergence is often very slow. They have presented a fast and independently written Monte Carlo method for cosmological parameter estimation named as 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. They have used an adaptive method for covariance calculation to calculate and update the covariance automatically as the chains progress. The analysis shows that the acceptance probability of each step in SCoPE is more than 95%, and the convergence of the chains are faster. SCoPE has been verified with cosmological parameter estimation with WMAP (and Planck - 2013). In another work, **Suvodip Mukherjee**, **Das** and **Souradeep** have used SCoPE to assess the cosmological parameters from joint analysis of Planck-2013 with BICEP2 and BOSS results.

Purely local origin of CMBR

Jayant V. Narlikar, in collaboration with Jean-Claude Pecker, Francois Ochsenbein and N. Chandra Wickramasinghe, has proposed a purely local origin of CMBR. This involves thermalization of local (mainly galactic) starlight by whisker dust grains. A plausible model can be constructed and verified under a few tests.

High Energy Astrophysics

X-ray spectral and timing characteristics

Gulab C. Dewangan and his collaborators Md. Shah Alam and S. Jhingan (both from Jamia Millia Islamia), Dipanjan Mukherjee (Australian National University), Aditya Mondal and B. Raychaudhuri (both from Visva-Bharti University) have studied the X-ray spectral and timing characteristics of an X-ray transient IGR J17497-2821 and its outburst on September 17, 2006. They have found that the source spectrum consisted of a hard powerlaw and a weak multi-colour disc blackbody with inner disc temperature of 200 eV. They have also detected a broad iron K-alpha line with FWHM of 27,000 km/s that can arise from an accretion disc truncated at large radius. The power density spectra of IGR J17497-2821 are characterized by broad-band noise components that are well modelled by three Lorentzians. The shallow powerlaw slope, low disc luminosity and the shape of the broad-band power density spectrum indicate that the source was in the low/hard state.

Aru Beri (IIT, Ropar), B. Paul (RRI, Bengaluru) and **Dewangan** have performed a pulse phase resolved spectroscopy of the complex emission lines around 1 keV in the unique accretion powered X-ray pulsar 4U 1626-67 using X-ray observations made with XMM-Newton. In this source, the red and blue shifted emission lines and the line widths measured earlier with Chandra suggest the origin of their accretion disk. Another possible signature of lines produced in accretion disk can be a modulation of the line strength with pulse phase. They have found the line fluxes to have pulse phase dependence, making 4U 1626-67 only the second pulsar after Her X-1 to show such variability. The O VII line at 0.568 keV from 4U 1626-67 varied by a factor of 4, stronger than the continuum variability, that support the origin of their accretion disk origin. The line flux variability may appear due to variable illumination of the accretion disk by the pulsar or more likely, a warp like structure in the accretion disk.

Time domain astronomy

Varun Bhalerao has continued his focus on time domain astronomy. As a part of the Intermediate Palomar Factory collaboration, he has contributed to the search of optical counterparts of gamma-ray bursts detected by the *Fermi* satellite.

He has been working with a JRF (Akshat Singhal) to create co-added deep reference images from Catalina Sky Survey data available at IUCAA. This will form the deepest all-sky reference catalogue. One of the many envisioned uses of such a catalogue is to provide a baseline image in the search for optical transients.

We have been working on a project to search for optical counterparts to unidentified *ROSAT* sources (with **Kaustubh Vaghmare** and visiting student Devraj Pawar).

NuSTAR

NuSTAR is the first focussing hard X-ray telescope to be flown in space. NuSTAR has an order of magnitude better angular resolution and is two orders of magnitude more sensitive than any other hard X-ray observatory. As a part of the science and instrument teams, **Varun Bhalerao** has been supporting observation planning and analysis pipeline testing. He has led the data analysis on IGR J17544–2619, a Supergiant Fast X-ray Transient. We have made the first magnetic field measurement for this family of sources, which settles a decade long phase of speculation about their field strengths. (Collaborators: J. Tomsick, P. Romano and others).

Quasars, Active Galactic Nuclei and Absorption Systems

Probing circumgalactic medium of high-redshift galaxies

The circumgalactic medium (CGM) is an astrophysical environment, which at any point in the evolution of a galaxy, provides clues to both its historical development and future evolution. To probe this, **Ravi Joshi** and collaborators have performed a detailed study of $\sim$ 80,000 associated galaxies of the very strong Mg II absorbers seen in SDSS/BOSS survey. A preliminary investigation of the nature of the two sets with $\mathcal{R}$ parameter ($\mathcal{R} \equiv W^{\lambda2600}_{\rm FeII}/W^{\lambda2796}_{\rm MgII}$) less or more than 0.45 represent the two physically different populations. We also have searched for the direct detections of any emission lines (e.g., [O II]$\lambda\lambda$3727, 3729 and [O III]$\lambda\lambda$4959, 5007) from intervening star-forming galaxies and found $\sim$ 122 such candidates (See Figure 12).

Finally, we aim to identify the galaxy counterparts of strong Mg II absorbers at low-z, and we have been allotted $\sim$ 14h observing time in 10 m SALT. This will essentially help us to understand their origin and establish whether the Mg II absorption with large velocity widths trace galactic outflows from star-forming galaxies or tidally stripped gas from galaxy interaction.

Extra-galactic backgrount light and γ-ray opacity

At any given epoch, the extragalactic background light (EBL) carries imprints of integrated star formation activities in the universe till that epoch. On the other hand, in order to estimate the EBL, when direct observations are not possible, one requires an accurate estimation of the star formation rate density (SFRD) and the dust attenuation (A_ν) in galaxies. **Vikram Khaire** and **R. Srianand** have presented a 'progressive fitting method' that determines global average SFRD(z) and $A_\nu(z)$ for any given extinction curve by using the available multi-wavelength multi-epoch galaxy luminosity

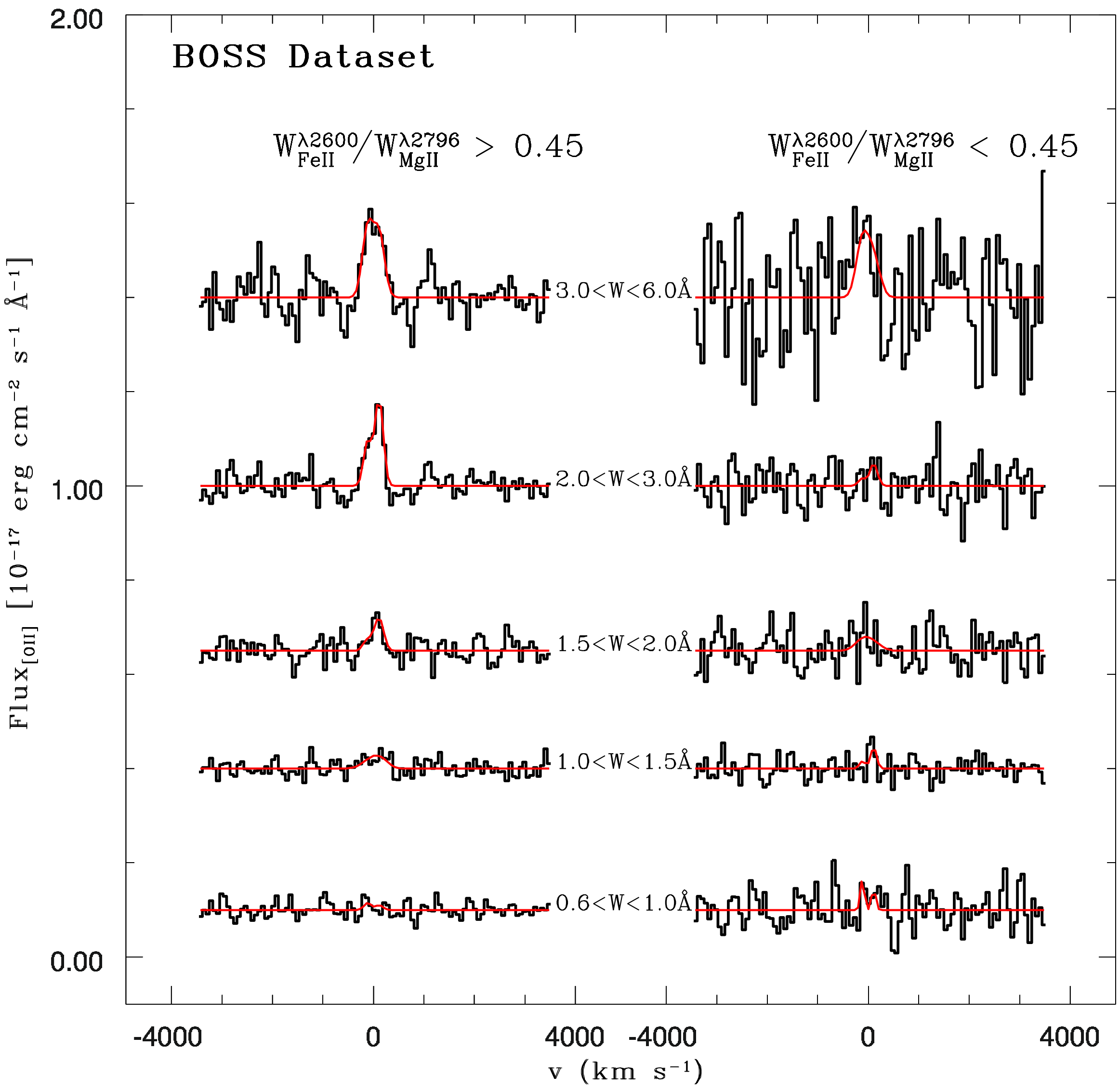


Figure 12: The [O II]$\lambda\lambda$3727 line spectral stack using SDSS-BOSS survey, for $\mathcal{R} \equiv W^{\lambda 2600}_{\rm FeII}/W^{\lambda 2796}_{\rm MgII} < 0.5$ (right) and > 0.5 (left). The red solid line is a double Gaussian fit to the data. The population with $\mathcal{R} > 0.5$ show the strong [O II]$\lambda\lambda$3727 line signature.

function measurements. Using the available observations, they have determined the best fitted combinations of SFRD(z) and $A_\nu(z)$, in a simple fitting form, up to $z \sim 8$ for five well known extinction curves. They have found that irrespective of the extinction curve used, the z at which the SFRD(z) peaks is higher than the z above which $A_\nu(z)$ begins to decline. For each case, they compute the EBL from ultra-violet to the far-infrared and optical depth (τ_γ) encountered by the high energy γ-rays due to pair production upon collisions with these EBL photons. They compare these with measurements of the local EBL, γ-ray horizon and τ_γ measurements using Fermi-LAT. All these and the comparison of independent SFRD(z) and $A_\nu(z)$ measurements from the literature with their predictions favour the extinction curve similar to that of Large Magellanic Cloud Supershell.

Time variability of low ionization BAL QSOs

R. Srianand, M. Vivek, Vijay Mohan and their collaborators (P. Petitjean, Ashish Mahabal and Saumyadip Samui) have presented results of time variability studies of Mg II and Al III absorption lines in a sample of 22 Low Ionization Broad Absorption Line QSOs (LoBAL QSOs) at $0.2 \leq z_{\rm em} \leq 2.1$ using the 2m telescope at IUCAA Girawali Observatory over a time-scale of 10 d to 7.69 years in the QSO's rest frame. Spectra are analysed in conjunction with photometric light curves from Catalina Real-Time Transient Survey. Long time-scale ($\geq$ 1 year) absorption line variability is seen in eight cases (36 per cent systems), while only four of them (18 per cent systems) show variability over short time-scales (< 1 year). They have noticed a tendency of highly variable LoBAL QSOs to have high ejection velocity, low equivalent width and low redshift. The detection rate of variability showing Fe fine-structure lines (FeLoBAL QSOs) is less than that seen in non-Fe LoBAL QSOs. Absorption line variability is more frequently detected in QSOs having continuum dominated by Fe emission lines compared to rest of the QSOs. Confirming these trends with a bigger sample will give vital clues for understanding the physical distinction between different BAL QSO sub-classes. They have correlated the absorption line variability with various parameters derived from continuum light curves and found no clear correlation between continuum flux and absorption line variabilities. However, sources with large absorption line variability also show large variability in their light curves. They also have seen appearance/disappearance of absorption components in two cases and clear indications for profile variations in four cases. The observed variability can be best explained by a combination of process driven by continuum variations and clouds transiting across the line of sight.

Metal poor DLAs

Rajeshwari Dutta, **R. Srianand** and their collaborators (P. Petitjean, Pasquier Noterdaeme and C. Ledoux) have presented a detailed high spectral resolution (R $\sim$ 40,000) study of five high-z damped Lyman alpha systems (DLAs) and one sub-DLA detected along four QSO sightlines. Four of these DLAs are very metal poor with [Fe/H] ≤ -2. One of them, at $z_{\rm abs}$= 4.20287 towards J0953−0504, is the most metal-poor DLA at $z > 4$ known till date. This system shows no enhancement of C over Fe and O, and standard population II star yields can explain its relative abundance pattern. The DLA at $z_{\rm abs}$= 2.34006 towards J0035-0918 has been claimed to be the most carbon-enhanced metal-poor DLA. However, they have shown that the thermal broadening is dominant in this system, and when this effect is taken into account, the measured carbon enhancement ([C/Fe] $= 0.45 \pm 0.19$) becomes $\sim$10 times less than what was reported previously. The gas temperature in this DLA is estimated to be in the range of 5000−8000 K, consistent with a warm neutral medium phase. From photoionization modelling of two of the DLAs showing C II* absorption, they have found that the metagalactic background radiation alone is not sufficient to explain the observed C II* cooling rate, and local heating sources, probably produced by in situ star formation are needed. Cosmic ray heating is found to contribute $\geq$ 60 per cent to the total heating in these systems. Using a sample of metal-poor DLAs with C II* measurements, they conclude that the cosmic ray ionization rate is equal to or greater than that seen in the Milky Way in $\sim$ 33 per cent of the systems with C II* detections.

HST/COS survey of low-z H_2

R. Srianand, in collaboration with Sowgat Muzahid and Jane Charlton has presented the results of a systematic search for molecular hydrogen (H_2) in low-redshift ($0.05 \leq z \leq 0.7$) damped Lyα absorbers (DLAs) and sub-DLAs with N(H II)$\geq 10^{19.0}$ cm^{-2}, in the archival Hubble Space Telescope/Cosmic Origins Spectrograph spectra. Their core sample is comprised of 27 systems with a median log N(H I) = 19.6. On the average, their survey is sensitive down to log $N(H_2)$ = 14.4 corresponding to a molecular fraction of log $f_{H_2} = -4.9$ at the median N(H I). H_2 is detected in 10 cases (3/5 DLAs and 7/22 sub-DLAs) down to this f_{H_2} limit. The H_2 detection rate of 50^{+25}_{-12} per cent seen in our sample, is a factor of 2 higher than that of the high-z sample of Noterdaeme et al., for systems with $N(H_2) > 10^{14.4}$ cm^{-2}. In spite of having N(H I) values typically lower by a factor of 10, low-z H_2 systems show molecular fractions (log $f_{H_2} = -1.93 \pm 0.63$) that are comparable to the high-z sample. The rotational excitation temperatures (T_{01} = 133 $\pm$ 55 K), as measured in our low-z sample, are typically consistent with high-z measurements. Simple photoionization models favour a radiation field much weaker than the mean galactic interstellar medium field for a particle density in the range 10 - 100 cm^{-3}. The impact parameters of the identified host-galaxy candidates are in the range $10 \leq \rho(kpc) \leq 80$. They, therefore, conjecture that the low-z H_2 bearing gas is not related to star-forming discs, but stems from self-shielded, tidally stripped or ejected disc-material in the extended halo.

H_2 and 21 cm absorption

Rajeshwari Dutta, **R. Srianand**, **Neeraj Gupta** and their collaborators (Sowgat Muzahid, Jane Charlton and Emmanuel Momjian) have presented a detailed analysis of a H_2-bearing metal-rich sub-damped Lyman alpha system at z_{abs}= 0.10115 towards the radio-loud quasar J0441-4313, at a projected separation of $\sim$ 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 $\leq$ 100 cm^{-3} and is subjected 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 $\leq$ 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 suggest that the gas may be tracing a recent metal-rich outflow from the host galaxy.

A low-z Ne VIII absorber

R. Srianand, Tanvir Hussain and their collaborators (Sowgat Muzahid, Anand Narayanan and Wakkar) have reported the detection of Ne VIII in a $z_{\rm abs}$= 0.59961 absorber towards the QSO PG1407+265 ($z_{\rm em}$ = 0.94). Besides Ne VIII, absorption from H I Lyman series lines (H I λ1025 - λ915), several other low (C II, N II, O II and S II), intermediate (C III, N III, N IV, O III, S IV and S V) and high (S VI, O VI and Ne VIII) ionization metal lines are detected. Disparity in the absorption line kinematics between different ions implies that the absorbing gas comprises of multiple ionization phases. The low and the intermediate ions (except S V) trace a compact ($\sim$ 410 pc), metal-rich (Z $\sim$ Z$_\odot$) and overdense (log n_H $\sim$ -2.6) photoionized region that sustained star formation for a prolonged period. The high ions, Ne VIII and O VI, can be explained as arising in a low density ($-5.3 \leq lognH \leq -5.0$), metal-rich ($Z \geq Z_\odot$) and diffuse ($\sim$ 180 kpc) photoionized gas. The S V, S VI and C IV (detected in the Faint Object Spectrograph (FOS) spectrum) require an intermediate photoionization phase with $-4.2 < logn_H < -3.5$. Alternatively, a pure collisional ionization model, as used to explain the previous known Ne VIII absorbers, with $5.65 < logT < 5.72$, can reproduce the S VI, O VI and Ne VIII column densities simultaneously in a single phase. However, even such models require an intermediate phase to reproduce any observable S V and/or C IV. Therefore, they conclude that when multiple phases are present, the presence of Ne VIII is not necessarily an unambiguous indication of collisionally ionized hot gas.

Solution to photon underproduction crisis

Understanding formation and evolution of baryonic structures in the universe, the galaxies and the intergalactic medium, is one of the main topics of present day physical cosmology. In order to address the issue, one needs to answer questions such as how star-formation proceeds, what is the resultant metal production and how it is related to the UV radiation field and molecular content of the gas. Absorption lines seen in the spectra of high-redshift quasars are very sensitive tracers of the gas whatever its location is, either dense regions as disks of galaxies or diffuse intergalactic clouds. This is, therefore, a unique tool to tackle the above mentioned problems. Besides, analysis of specific absorption lines can be used as a probe for studying the time evolution of cosmic microwave background radiation and dimensionless fundamental physical constants.

Vikram Khaire and his collaborators have investigated the recent claim of photon underproduction crisis by Kollmeier et al. (2014), which suggests that the known sources of ultra-violet (UV) radiation may not be sufficient to generate the inferred hydrogen photoionization rate (Γ_{HI}) in the low redshift inter-galactic medium. Using the updated QSO emissivities from the recent studies and our cosmological radiative transfer code developed to estimate the UV background, we have shown that the QSO contribution to Γ_{HI} is higher by a factor 2 as compared to the previous estimates. Using self-consistently computed combinations of star formation rate density and dust attenuation, it is shown that a typical UV escape fraction of 4% from star forming galaxies should be sufficient to explain the inferred HI by Kollmeier et al. (2014). Interestingly, it is found that the contribution from QSOs alone can explain the recently inferred Γ_{HI} by Shull et al. (2015), which used the same observational data but different simulation. Therefore, we have concluded that the crisis was not as severe as it was perceived before and there seems no need to look for alternate explanations such as low luminosity hidden QSOs or decaying dark matter particles. This is part of **Vikram Khaire's** thesis.

IGM heating by QSOs

Using hydrodynamical simulations coupled to a radiative transfer code, **Hamsa Padmanabhan** and collaborators have studied the additional heating effects in the intergalactic medium (IGM) produced by $z \sim 6$ quasars in their near-zones. If helium is predominantly in He II to begin with, both normalization (T_0) and slope (γ) of the IGM effective equation-of-state get modified by the excess ionization from the quasars. Using the available constraints on T_0 at $z \sim 6$, we discuss implications for the nature and epoch of H I and He II reionization. They have studied the extent of the He III region as a function of quasar age and show for a typical inferred age of $z \sim 6$ quasars (i.e., $\sim 10^8$ yr), it extends up to 80 per cent of the H I proximity region. For these long lifetimes, the heating effects can be detected even when all the H I lines from the proximity region are used. Using the flux and curvature probability distribution functions (PDFs), we study the statistical detectability of heating effects as a function of initial physical conditions in the IGM. For the present sample size, cosmic variance dominates the flux PDF. The curvature statistics is more suited to capture the heating effects beyond the cosmic variance, even if the sample size is half of what is presently available. This is part of **Hamsa Padmanabhan's** thesis.

Equation of state of the IGM

Using hydrodynamical simulations, **Hamsa Padmanabhan** and collaborators have explored the use of mean and percentiles of the curvature distribution function to recover the equation of state of the high-z ($2 < z < 4$) intergalactic medium (IGM). They have found that the mean and percentiles of the absolute curvature distribution exhibit tight correlation with the temperatures measured at respective characteristic overdensities $\overline{\nabla}_{iS}$ at each redshift. Hence, they have provided complementary probes of the same underlying temperature-density distribution, and can in principle be used to simultaneously recover both parameter T_0 and γ of the IGM effective equation of state. They have quantified the associated errors in the recovered parameters T_0 and γ from the intrinsic scatter in the characteristic overdensities and the uncertainties in the curvature measurement. This is another part of **Hamsa Padmanabhan's** thesis.

Lost in secular evolution: The case of a low mass classical bulge

The existence of a classical bulge in disk galaxies holds important clue to the assembly history of galaxies. Finding observational evidence of very low-mass classical bulges particularly in barred galaxies including our Milky Way, is a challenging task as the bar driven secular evolution might bring significant dynamical change to these bulges alongside the stellar disk.

Using high-resolution N-body simulation, **Kanak Saha** and collaborators have shown that if a cool stellar disk is assembled around a non-rotating low-mass classical bulge, the disk rapidly grows into a strong bar within a few rotation time scales. Later, the bar driven secular process transform the initial classical bulge into a flattened rotating stellar system, whose central part also have grown a bar-like component rotating in sync with the disk bar. During this time, a boxy/peanut (hereafter, B/P) bulge is formed via the buckling instability of the disk bar and the vertical extent of this B/P bulge being slightly higher than that of the classical bulge, it encompasses the whole classical bulge. The resulting composite bulge appears to be both photometrically and kinematically identical to a B/P bulge without any obvious signature of the classical component. The analysis suggests that many barred galaxies in the local universe might be hiding such low-mass classical bulges, and suggests that stellar population and chemodynamical analysis might be required in establishing the evidence for such low-mass classical bulges.

Spin up of massive classical bulges during secular evolution

Classical bulges in spiral galaxies are known to rotate faster than ellipticals of same luminosities but much slower than the pseudo-bulges that form via buckling instability. However, the origin of angular momentum in classical bulges remain unclear

Kanak Saha and collaborators have used self-consistent N-body simulations to study the

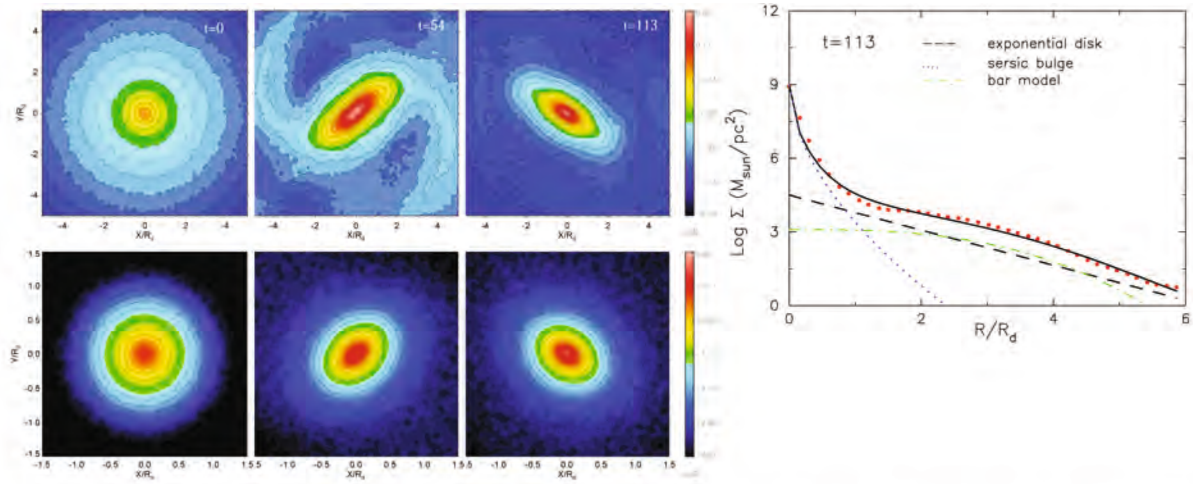


Figure 13: The upper left panel shows surface density maps of stars including disk stars and classical bulge stars. Lower left panel shows that of the classical bulge stars alone. The figure on the right panel shows the 3-component decomposition of the surface density profile and shows no evidence of a classical bulge.

interaction of massive classical bulges (ClBs) with a bar that forms self-consistently in the disc. They have shown that the ClB gains significant angular momentum from the bar, which surprisingly, scales approximately linearly with the ClB mass. It is also tightly correlated with the ratio of the bulge size to the bar size. Most of the angular momentum gain occurs via low-order resonances, particularly 5 : 2 resonant orbits. A density wake forms in the ClB which co-rotates 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 in the ClB. The induced rotation is small in the centre but significant beyond ~ 2 bulge half mass radii, where it leads to mass-weighted $V/\sigma \sim 0.2$, and reaches a local $V_{\rm max}/\sigma_{\rm in} \sim 0.5$ at around the scale of the bar. In all models a box/peanut bulge also forms suggesting that composite bulges may be common (See Figure 13).

This is an ongoing collaboration with Ortwin Gerhard (MPE, Germany) and Inma Martinez-Valpuesta (IAC, Spain).

Thick disk formation induced by a strong bar phase

Most spiral galaxies including our Milky Way host a thick disk in addition to the underlying cold thin disk. Various observations suggest that such a thick disk is comprised of a hotter comparatively more diffused stellar population, extending to larger heights above the disk midplane. Although, many mechanisms have been proposed for its formation, the issue on the origin of thick disk is not settled yet. Using the known barred galaxy dynamics and N-body simulations, **Kanak Saha** and Daniel Pfenniger (Geneva Observatory, Switzerland) have identified an in-escapable and efficient internal process to feed a thick disk population. This process must occur whenever a bar forms and exceeds for a while at a strength threshold. Indeed, beyond a critical bar strength, the bar co-rotation region becomes fully unstable, which is characterized by calculating the Lagrange's points stability parameters. Then $L_{4,5}$ becomes unstable in addition to $L_{1,2}$, which means that the whole co-rotation region phase space becomes chaotic. This leads first to a rapid horizontal diffusion of all the co-rotation stars. Over longer time-scales, these stars are progressively heated

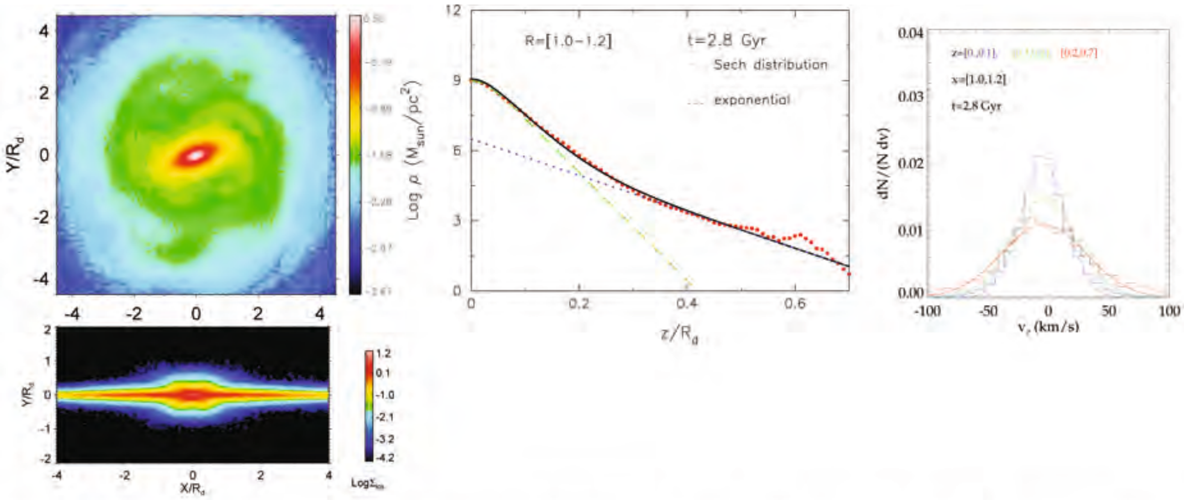


Figure 14: Line of sight density maps of the model galaxy at t=2.8 Gyr. Initial model was axisymmetric as shown in the above left figure, and vertical density distribution was characterized by $sech^2$ profile. In the middle figure, we have shown the vertical density distribution and its 2-component decomposition into a thin and thick disks. On the extreme right, we have shown the vertical velocity distribution at different heights above the midplane (z = 0) of the galaxy.

vertically while moving inside co-rotation, where the same strong vertical resonances related to the formation of peanut-shaped bar/bulge exist. This process is related, but distinct and more efficient than the mechanism identified by Sellwood and Binney for explaining radial mixing in disks through transient spiral waves, because only a bar perturbation can be strong enough to fully destabilize the whole co-rotation region. The resulting hot stellar population consists initially of chaotic orbits with Jacobi constants large enough to visit, according to Arnold's topological argument, all the chaotic phase space. If the bar strength decreases with time, some of these chaotic orbits can subsequently be trapped by regular phase space regions characterized then by adiabatic invariants suited for a thick disk population (See Figure 14).

Interstellar extinction with small size silicate and PAHs

In a recent work on analytical modelling of interstellar extinction with small size grains consisting of silicates/graphites and PAHs, **Ranjan Gupta** and collaborators have found that ultra small PAHs play an important role in the FUV part of the interstellar extinction curve.

The Figure 15 shows the extinction spectrum profile for bulk PAHs compared with that of equal volume and equal mass ultra (small) silicate grains.

In continuation of the work on modelling silicate $10\mu m$ feature, we have fitted the IR spectra with new models (Si+SiC) as shown in Figure 16 (a sample of 4 fits from a total of about 700 such IRAS objects).

Classification of variable stars with automated schemes

Under an INDO-US joint forum centre, **Ranjan Gupta** and collaborators have developed several automated classification schemes for variable stars from OGLE-III IR very large data set of 108193 light curves. Figure 17 shows the set of different light curves, where the dots are the original raw light curve data and the continuous line is after pre-processing stages. Raw light curves are

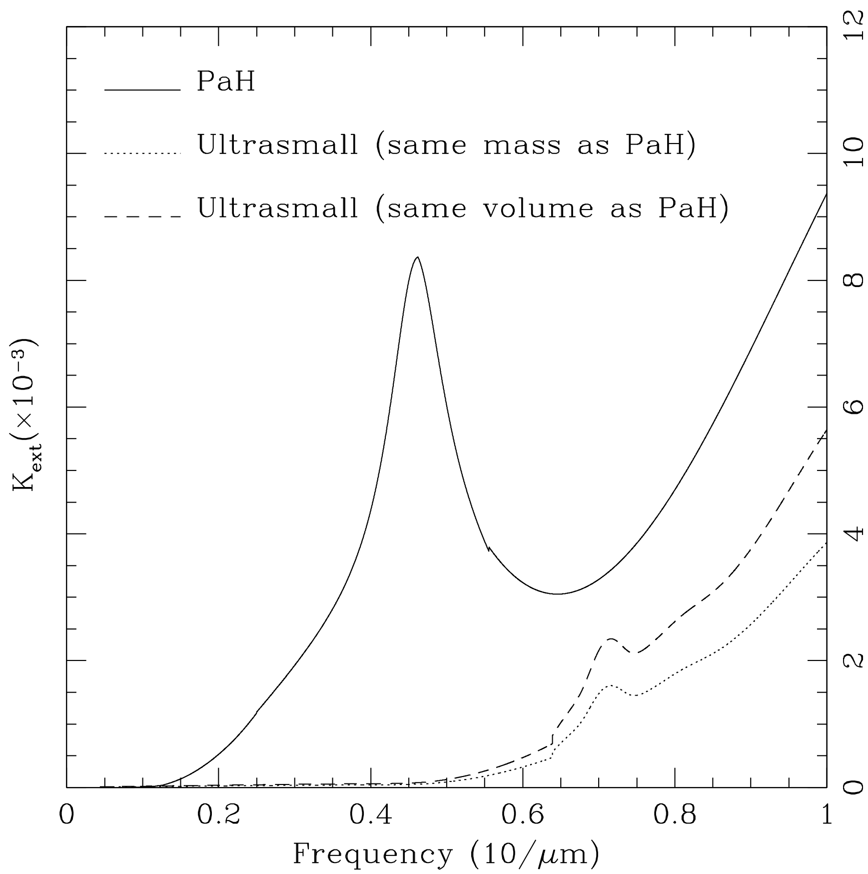


Figure 15: Extinction spectrum profile for bulk PAHs compared with that of equal volume and equal mass ultra (small) silicate grains

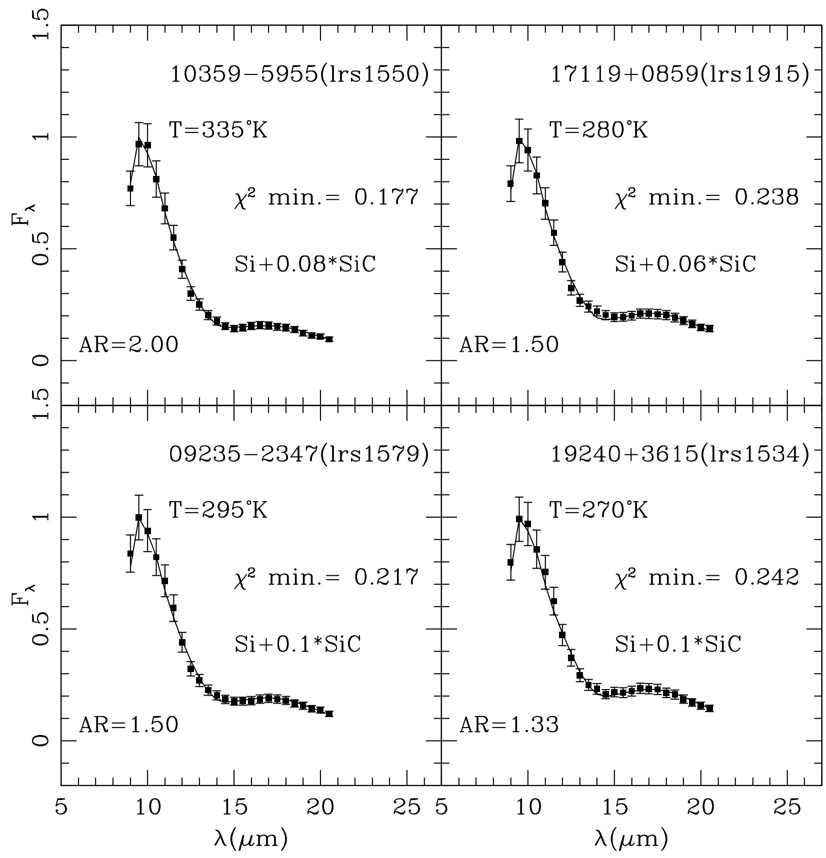


Figure 16: Best fits to Model v/s IRAS NIR Spectra

phased with the period of the star with phase 0 at minimum magnitude/maximum brightness. Phased light curves are then interpolated to get 100 equally spaced magnitudes between phase 0 and 1 for all stars.

The set of reduced and processed light curve data has been then used for classification into seven variable types, using several automated schemes like: (i) Support Vector Machine, (ii) Naive Bayes, (iii) Random Forest, (iv) Artificial Neural Networks, and (v) Tree. Figure 18 shows the performance of these different schemes, and the Tree classifier provides the highest efficiency of better than 92% correctly classified light curves.

Solar Physics

Variable gravity and the faint young Sun paradox

Solar models suggest that four billion years ago the young Sun was $\sim$ 25% fainter than it is today, rendering Earth's oceans frozen and lifeless. However, there is ample geophysical evidence that Earth had a liquid ocean teeming with life 4 Gyr ago. Since $\mathcal{L}_\odot \propto G^7 M_\odot^5$, the Sun's luminosity $\mathcal{L}_\odot$ is exceedingly sensitive to small changes in the gravitational constant G. **Varun Sahni** and Yuri Shtanov have shown that a percent level increase in G in the past would have prevented Earth's oceans from freezing, resolving the *faint young Sun* paradox. Such small changes in G are consistent with observational bounds on $\Delta G/G$. Furthermore, a time dependent gravitational constant is associated with several modified gravity models including those with a Kaluza-Klein perspective. Furthermore, since $\mathcal{L}_{\rm SNIa} \propto G^{-3/2}$, an increase in G leads to fainter supernovae, creating tension between standard candle and standard ruler probes of dark energy. Precisely such a tension has recently been reported by the Planck team.

The evolution of the emission measure distribution in the core of an active region

Thermal distribution of the plasma and the time-scale of energy release in coronal structures reveals the important information regarding the heating processes at work in that particular structure. High (low) frequency heating occurs when the duration between successive heating events is smaller (larger) than the cooling time, as was defined by **Durgesh Tripathi**, et al. (2011). In the high-frequency heating scenario, the plasma does not have enough time to cool sufficiently and produces a narrow emission measure (EM(T)) distribution with a steep slope in the 13 MK range. However, in the low frequency heating scenario, since the time duration is larger than the cooling time, the plasma has sufficient time to cool down before being heated again. Hence, there would be a substantial amount of material at cooler temperatures giving rise to comparatively shallower slopes. The models however, generally, predict that low-frequency nanoflares can only account for slopes that are below 3.

Using the observations recorded by the Extreme-ultraviolet Imaging Spectrometer (EIS) on board Hinode Solar Mission, Del Zanna, **Tripathi**, Helen Mason et al. (2014) have studied the spatial distribution and evolution of the slopes of the of the EM(T) curves between 1-3 MK in the core of an active region AR 11193, twice during the complete life time, once when it appeared on the solar centre (See Figure 19) and then again when it came back after the complete rotation (See Figure 20). The results showed that there were significant variations in the slopes at different spatial locations within the active region. The slope for a given region changed from 4.4 to 4.6 from the first rotation to the second rotation. These results suggest that the EM distribution in the active region cores is generally with high frequency heating.

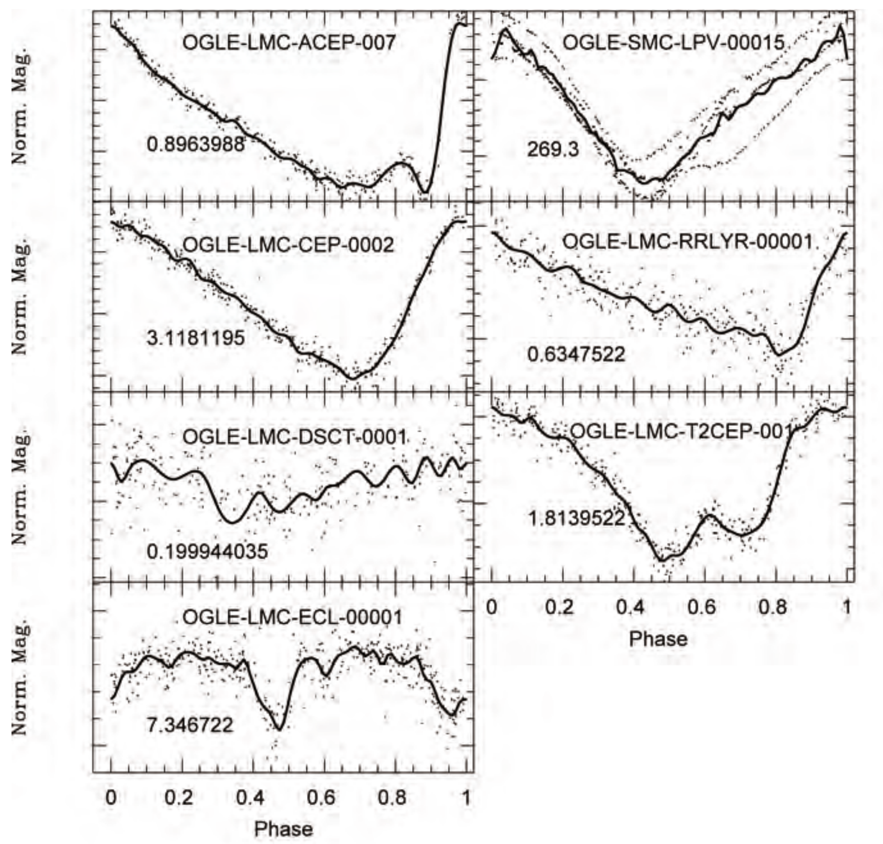


Figure 17: Light curves of seven classes

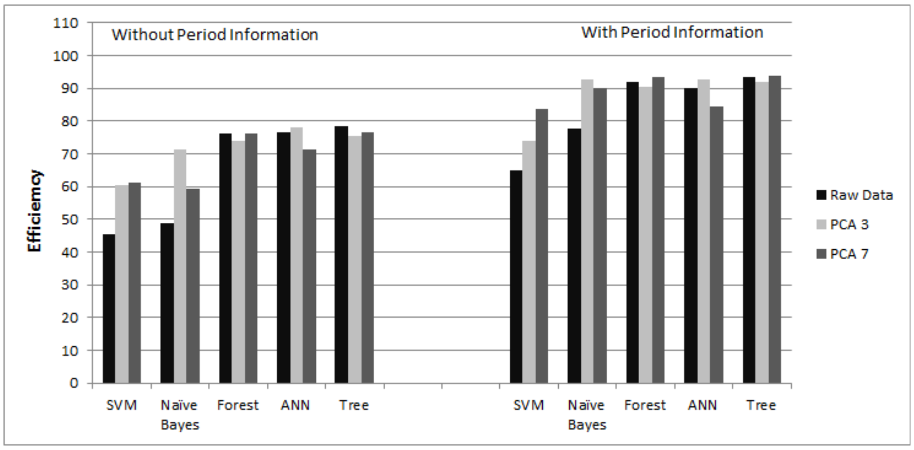


Figure 18: Light curves of seven classes

Emission measure distribution for diffuse regions in solar active regions

The heating and maintenance of solar corona at 1 MK remains to be a mystery since its discovery in 1940, and is still far from being comprehensive. For probing the underlying heating processes, active regions (ARs) are ideal targets as they show the locations of profound heating and they have a wide distribution of physical parameters. It is of critical importance to accurately measure such parameters for the formulation and providing constraints of theories of coronal heating. Topologically, there are various structures in ARs, namely: the core loops primarily seen at 35 MK rooted in 1-2 MK moss regions, MK warm loops, and the cool (< 1MK) fan like loop structures seen at the edges of the ARs. Moreover, there is substantial amount of diffuse emission in and around the active regions in addition to the different loop structures mentioned above. These emission regions may be defined as that with no resolvable structures. However, they may appear loop-like at higher resolutions. It has also been noted earlier that the well defined loop structures are just about 20 - 30% higher than the diffuse emission seen in the background/foreground.

Srividya Subramanian, Durgesh Tripathi, Helen Mason and James Klimchuk (2014) have investigated two active regions in off-limb location, namely, AR 10939 and AR 10961, and probed the temperature structure using differential emission measure techniques and inferred underlying heating mechanisms (See Figure 21). We have made use of the spectral observations from the Extreme-ultraviolet Imaging Spectrometer (EIS) on board Hinode. These results reveal that the EM distributions of the diffuse emission regions have a characteristic peak at log T = 6.25, and with a cool-ward slopes of about 1.4 – 3.3. These results also suggest that both low as well as high-frequency nanoflare heating events are at work. Moreover, these results provide additional constraints on the properties of these diffuse emission regions and their contribution to the background/foreground when active region cores are observed on-disk.

Spectroscopic observations of a coronal loop: Basic physical plasma parameters along the full loop length

Coronal loops are the basic building blocks of the solar transition region and the corona. The mechanism behind plasma filling, dynamic flows and coronal heating remain a mystery. The mechanism(s) must be stable enough to continue to feed the coronal with chromospheric plasma

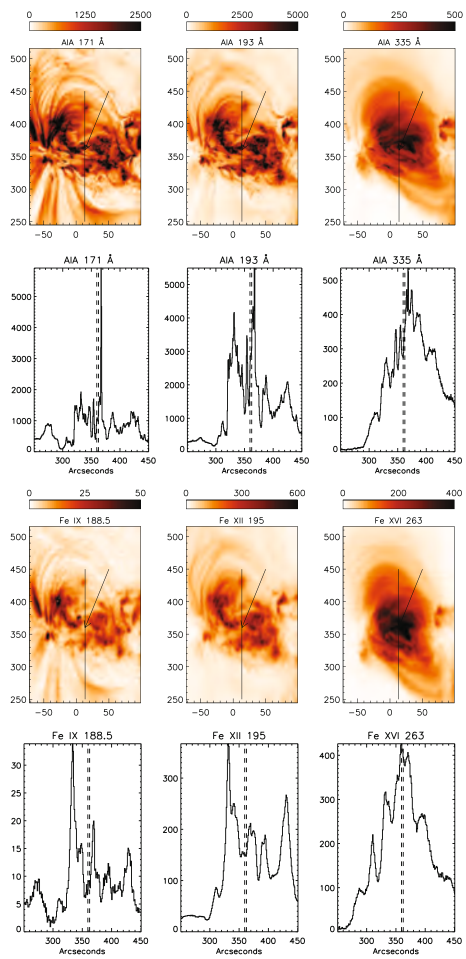


Figure 19: AIA (DN/s, first and second row) and EIS (radiances in photon cm^{-2} st^{-1} s^{-1}, third and fourth row) negative images on April 19, 2011. The arrows indicate the AR core region selected for DEM analysis. The bottom plots show the profiles of the intensities along this vertical line. The dashed vertical lines indicate the region selected for DEM analysis (From Del Zanna, **Durgesh Tripathi**, Helen Mason, et al. 2015).

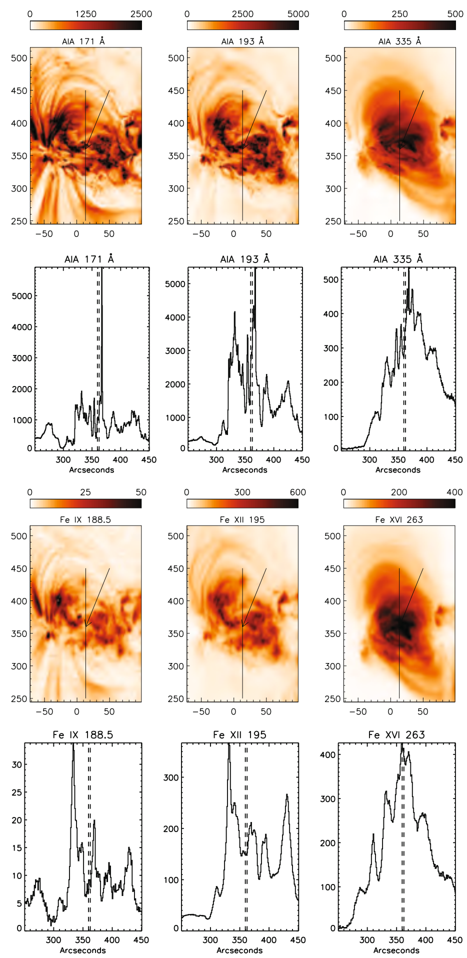


Figure 20: Same as the Figure 19, for the May 17, 2011 second rotation (From Del Zanna, Tripathi, Mason, et al. 2015).

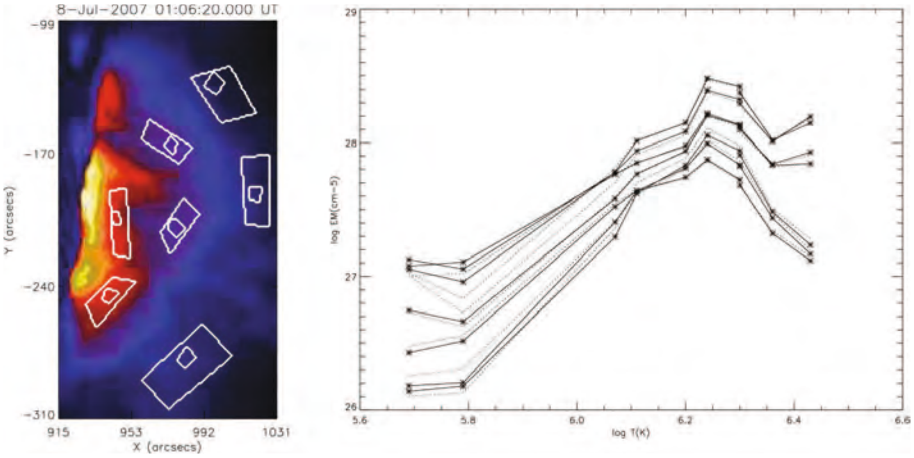


Figure 21: Left: Intensity image of AR 10961 in FeXIII with the chosen masked regions over-plotted with white boxes. Right: Emission measure curves of all the masked regions, where continuous and dotted lines represent masked regions enclosed by the bigger boxes and sub-boxes, respectively. The overall pattern of the EM curve for all the regions are very similar and that the peak EM of diffuse regions peak at log T = 6.25.

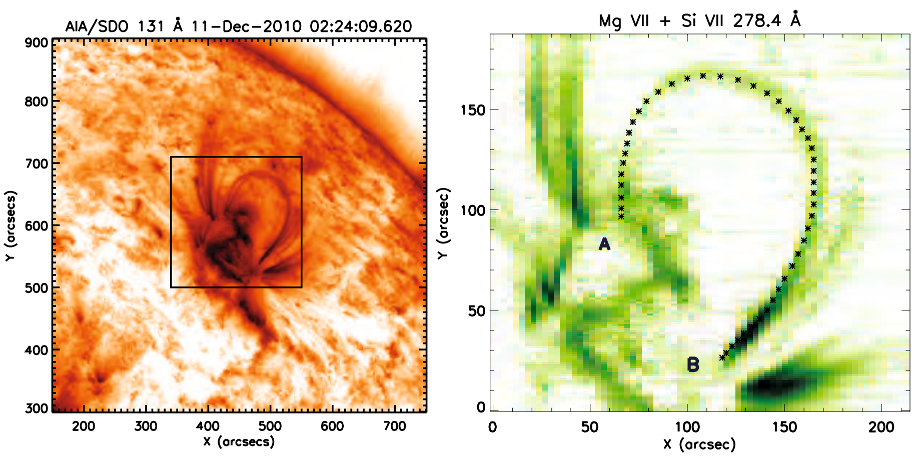


Figure 22: Left: A portion of the Suns disk showing the active region AR 11131 in the 131 Å passband. The box indicates the region that was rastered by EIS/Hinode. Right: The traced coronal loop from left foot-point A to the right foot-point B as seen in the Mg VII 278.39 Å(blended with Si VII 278.44 Å spectral line.)

and able to heat the plasma to over 1 MK in a rather short span of distance between the chromosphere and transition region. This problem makes coronal loops an interesting target for detailed study. For the first time, a coronal loop was observed in its full length in various spectral lines using an spectroscopic instrument called the Extreme-ultraviolet Imaging Spectrometer (EIS) on-board Hinode (See Figure 22). **Girjesh Gupta, Durgesh Tripathi** and Helen Mason (2015) have derived physical plasma parameters such as electron density, temperature, pressure, column depth, and filling factors along the loop length from one foot-point to another. The obtained electron density along the coronal loop from the Mg VII line pair was compared with the hydrostatic equilibrium model at an isothermal temperature of 0.73 MK, which was obtained from EM-loci method. They have found that the observed densities in the left segment of the loop were lower (i.e., under-dense) than that expected from isothermal hydrostatic model. However, it was higher (i.e., over-dense) for the right segment of the loop (See Figure 23). This suggests a non-symmetric density profile along the loop. These new measurements of physical plasma parameters, from one foot-point to another, provide important constraints on the modelling of the mass and energy balance in the coronal loops.

Observational evidence of dissipation of slow magneto-acoustic waves in polar coronal holes

Girjesh Gupta (2014) has focused on polar coronal hole region to find any evidence of dissipation of propagating slow magneto-acoustic waves using the space based data obtained using AIA onboard SDO (See Figure 24). We have obtained time-distance and frequency-distance maps along plume structure in polar coronal hole. We also have obtained Fourier power maps of polar coronal hole in different frequency ranges in 171 Å and 193 Å passbands. We have found the presence of propagating slow magneto-acoustic waves having temperature dependent propagation speeds. The analysis showed that low-frequency waves travel longer distances (longer detection length) as compared to high-frequency waves (See Figure 25). We have found two distinct dissipation length scales of wave amplitude decay at two different height ranges (between 0 − 10 Mm and 10 − 70 Mm) along the observed plume structure. Dissipation length obtained at higher height range shows some frequency dependence. Propagating slow magneto-acoustic waves are getting heavily damped (small dissipation length) within the first 10 Mm distance. Frequency dependent dissipation length of wave propagation at higher heights may indicate possibility of wave dissipation due to thermal conduction, however, contribution from other dissipative parameters can not be ruled out. Individual Fourier power spectra obtained at several locations, indicated the clear powerlaw distribution. Because of powerlaw distribution, low-frequency waves always have high power content as compared to high-frequency waves, and thus, are able to travel longer distances (longer detection lengths) comparatively. Results presented in this study are of great importance in the theoretical modelling of coronal heating and acceleration of the fast solar wind in the coronal holes.

Sunspot waves and triggering of homologous active region jets

Ramesh Chandra, **Girjesh Gupta, Sargam Mulay** and **Durgesh Tripathi** (2015) have carried out multi-wavelength observations of five homologous recurrent solar jets occurred in active region NOAA 11133 on December 11, 2010. These jets were well observed by the Solar Dynamic Observatory (SDO) with high spatial and temporal resolution (See Figure 26). The speed of the jets ranged between 86 and 232 km/s, and type III radio bursts were observed in association with all the five jets. The investigation of the over all evolution of magnetic field in the source regions suggested that the flux was continuously emerging on longer term. All the jets but J5 were triggered during the local dip in the magnetic flux, suggesting the launch of the jets during localised sub-mergence/cancellation of magnetic

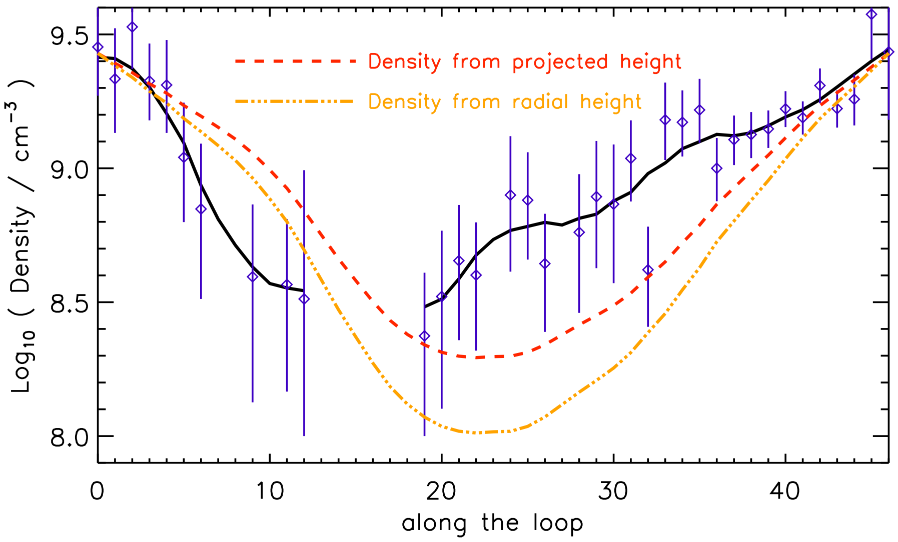


Figure 23: Comparison of density as measured using Mg VII (280.75/278.39) line ratio (plotted with diamond symbol and 5-point running average with continuous line) from left foot-point A to right foot-point B with density expected from a hydrostatic model at temperature 0.73 MK obtained from projected (dashed line) and radial (dot-dashed line) heights of the loop.

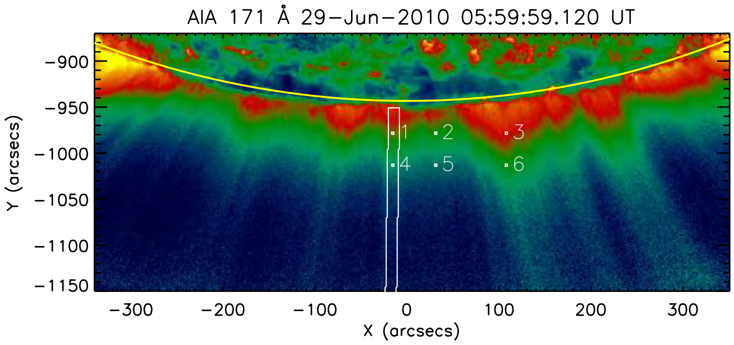


Figure 24: Context map of a south polar coronal hole from AIA/SDO 171 Å passband. The continuous white line box in off-limb region indicates the selected plume region for detailed analysis. To make the far off-limb structures visible, a radial enhancement filter is applied on the image.

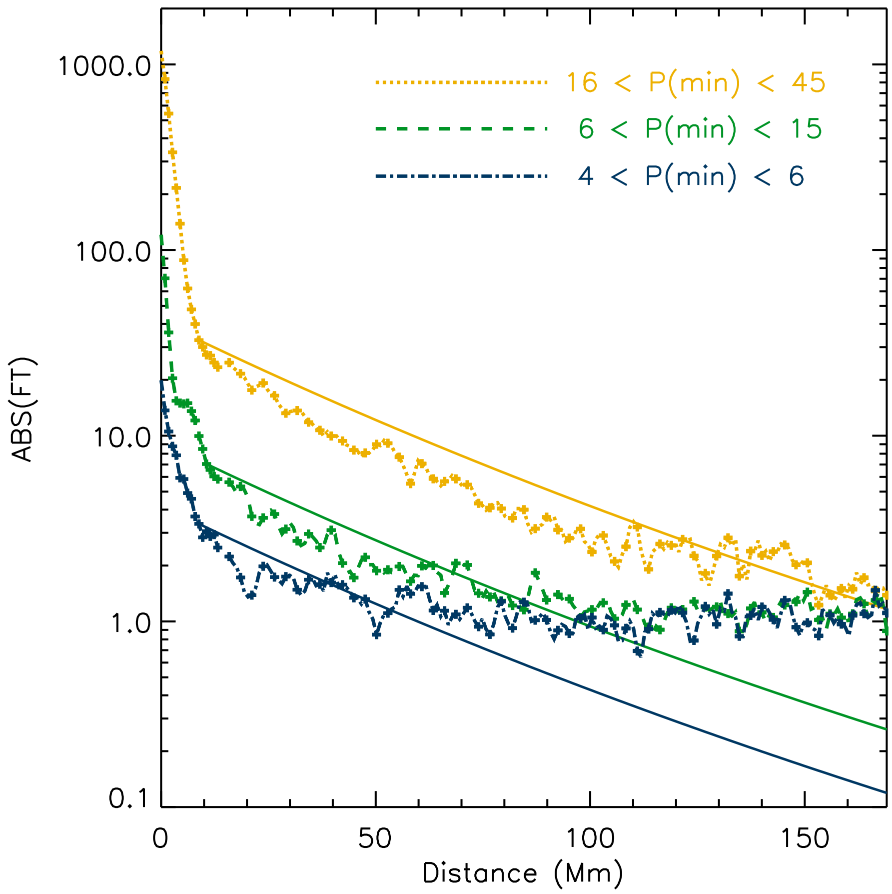


Figure 25: Variation of Fourier transform (FT) values with height in different period (frequency) ranges as marked with different colours. Dotted lines indicate the observed decrease with height, whereas continuous lines are expected theoretical curves for undamped wave propagation.

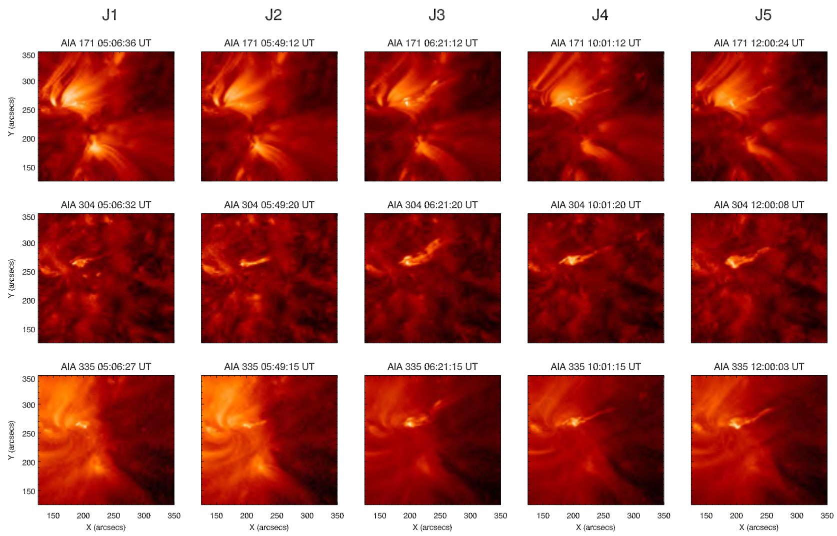


Figure 26: Peak phase of five homologous jets, i.e., J1, J2, J3, J4, and J5 observed by the Atmospheric Imaging Assembly on board the Solar Dynamics Observatory at 171, 304, and 335 Å.

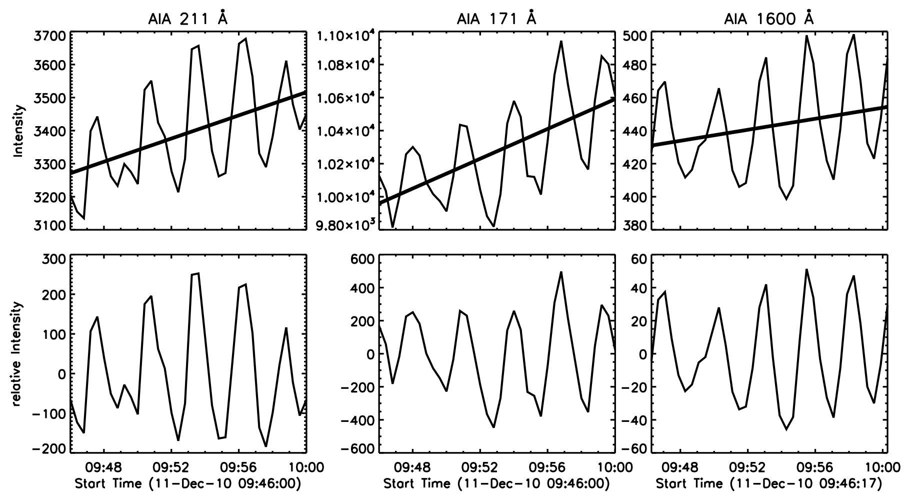


Figure 27: Top panels: Intensity variation just before jet J4 event observed in AIA 211, 171, and 1600 Å passbands. Over-plotted continuous lines are linear fits applied to the intensity variation. Bottom panels: Relative intensity variation with time obtained after subtracting the linear trend (fit) from the original intensity for the different AIA passbands as labelled. Relative intensity variation with time in different passbands clearly show the increase in amplitude of wave oscillations prior to the jet event J4.

flux. Additionally, they have found that all the jets were ejected in the direction of open field lines as was revealed by the potential field source surface modelling of the photospheric magnetic flux. They have also traced sunspot oscillations from the sunspot interior to foot-point of jets and found the presence of 3 minute oscillations in all the AIA passbands. This analysis revealed the increase in the amplitude of oscillations just before the trigger of the jets (See Figure 27). The amplitude of oscillations decreased after the jets were triggered. These observations provide yet another evidence in favour of re-connection model for trigger of the jets. However, the observations of increased oscillatory power and its subsequent decrease provides evidence of wave-induced re-connection triggering the jets.

Initiation of coronal mass ejections event: Multi-wavelength perspective

One of the major unsolved problems in solar physics is that of coronal mass ejection (CME) initiation. Recently, **Sargam Mulay, Srividya Subramanian**, **Durgesh Tripathi** et al. (2015) have studied the initiation of a flare-associated CME that occurred on November 3, 2010 using multi-wavelength observations recorded by the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory (SDO) and the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI).

In these observations, an inflow structure initially in the 304 Å (dominated by chromospheric He II at quiet conditions) and a few seconds later in the 1600 Å (dominated by C IV emission transition region temperature and the continuum emission from the photosphere) images have been detected. This strongly suggested the heating of the inflow structure, which was also demonstrated by the increase in brightening of the inflow structure in the 304 Å observations (See Figure 28).

A bubble-like structure, which later became a flux-rope-like structure and erupted as CME, started to rise in the 131 Å (dominated by coronal Fe VIII, Fe XX and Fe XXIII) images exactly at the time when the inflow structure was first seen. This inflow structure was detected as one of the legs of the CME (See Figure 29).

They have also observed a 1840 keV non-thermal compact source concurrent and near co-spatial with the brightening and movement of the inflow structure (See Figure 28). The spectral analysis of the source suggests the non-thermal nature of the source, demonstrating the magnetic reconnection processes to be responsible for the HXR emission. The appearance of this compact non-thermal source, brightening, and movement of the inflow structure and the subsequent outward movement of the CME structure in the corona led us to conclude that the CME initiation was caused by magnetic re-connection. Moreover, for the first time, they have observed signature of magnetic reconnection in lines like 304 A and 1600A. Such observations may have the potential to provide information on reconnection processes occurring in partially ionized plasmas.

Observations and modelling of North-South asymmetries using flux transport dynamo

From previous observations of sunspots and poloidal field on the surface of the Sun, we know that the Sun goes from a phase of maximum activity to minimum activity over an average of 11 years. This cycle can be considered as a continuous change between toroidal and poloidal magnetic fields, often assisted by meridional circulations. The sunspots and the active regions (ARs) are known to represent the toroidal field. Juie Shetye, **Durgesh Tripathi** and Mausumi Dikpati (2015) concentrated on understanding the asymmetries in the Northern-Southern hemispheres on the Sun in terms of magnetic field. Figure 30 shows how the AR magnetic flux changes along the complete solar cycle. The Northern hemisphere is represented by black line and Southern hemisphere is represented by red line. We see that the Northern hemisphere is dominant over most of SC 23, whereas Southern hemisphere dominates the declining phase of SC 23. Also SC 24 started at different times in both hemispheres. This behaviour gives us the hint that solar hemispheres are loosely coupled and may act independently. Further, the dominance of the

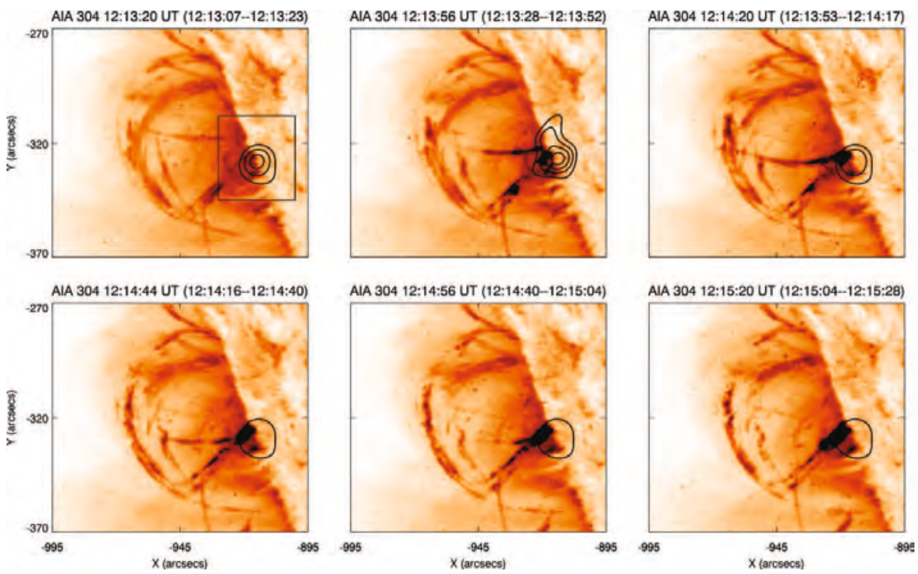


Figure 28: Sequence of images observed during the rise phase of CME initiation at 304 Å colour inverted, with RHESSI contours over-plotted in the 1840 keV energy band. The contours in each frame correspond to the ratio of the hard X-ray (HXR) flux observed in that particular frame with respect to the peak flux observed in the whole event. The top middle panel corresponds to the peak of the HXR light curve. The contours are 30%, 50%, 70%, and 90% of the maximum flux in the top middle image.

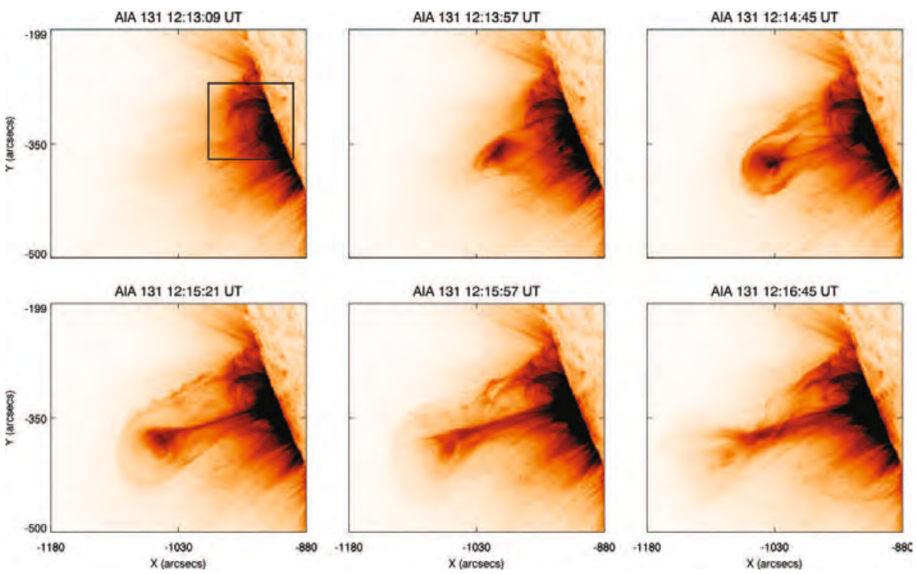


Figure 29: Composite images of observations recorded in 304 Å (green) and 131 Å (red).

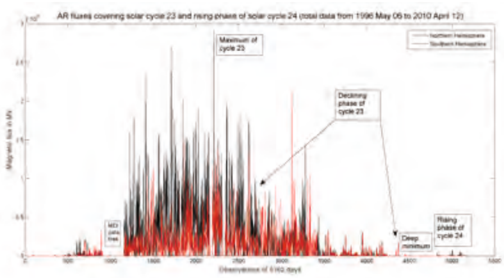


Figure 30: Comparison of AR flux behaviour between the Northern and the Southern hemispheres from May 06, 1996 to March 10, 2010.

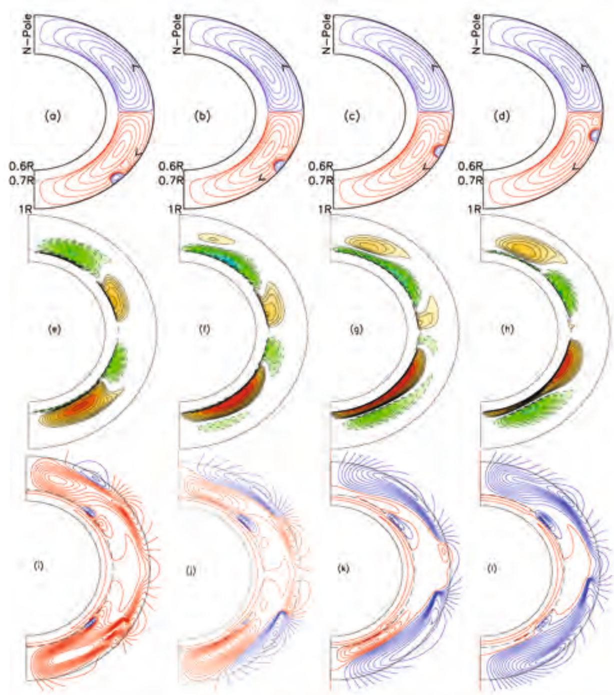


Figure 31: Top panels (a-d): Snapshots of streamlines at four epochs within a sunspot cycle due to drifting of inflow cells from mid-latitude to the equator. Note that the South has stronger inflow cells in this simulation. Middle panels (e-h) show the snapshots of dynamo-generated toroidal fields at the same four epochs; red denotes positive field (going into the plane of the paper) and blue negative field (coming out of the plane of the paper). Bottom panels (i-l) show the poloidal field lines; red denote positive (clockwise) and blue negative (anti-clockwise).

Southern hemisphere during final stages of SC 23 could have delayed the rise of SC 24.

This information was used in a flux transport dynamo where additional inflows (AR fluxes - 10 times stronger than Northern hemisphere) were added in the Southern hemisphere (See Figure 31). We see in panel (i) there is an immediate effect on the surface poloidal field in the South. Each column in Figure 30 is separated by 2.7 years. The top row shows how the inflows migrate towards the equator, the middle row shows toroidal fluxes and lower most row shows poloidal fluxes. By counting the number of contours of poloidal field lines, we can see this effect in the form of more concentrated flux in the neighbourhood of the inflow pattern. Because the extra inflow near the surface is slowing down the migration of poloidal flux toward the pole, by panel (j) 2.7 years later, the polar field in the South is weaker and is reversing sign later than in the North. Again the number of contours reveals that these results in less poloidal flux being transported to the bottom in high latitudes to cancel out the previous poloidal fields. This, in turn allows the toroidal field near the bottom in the South to become significantly stronger than in the North. Therefore, the stronger inflows associated with one cycle in one hemisphere can lead to stronger toroidal fields in that hemisphere in the next cycle. These asymmetries persist for more than one solar cycle.

Instrumentation

Ultra Violet Imaging Telescope (UVIT)

S. N. Tandon and his collborators have been working on the Ultra Violet Imaging Telescope (UVIT), which is one of the 5 instruments to go on ASTROSAT satellite. UVIT makes 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) and the total field of view is $\sim 28'$. It is being developed through a collaboration between several Indian institutions: IIA, ISRO, IUCAA, and TIFR, and Canadian Space Agency.

During this year, the detector for visible channel was replaced by a new piece (the old detector was damaged during the vibration tests) and the telescope reassembled and tested at IIA, Bengaluru. After this, the payload went through thermal-vacuum test successfully in November 2014, before being assembled on the satellite in January 2015.

In the next few months, the payload would be electrically integrated with the satellite and tested. After the environmental tests, ASTROSAT is expected to be launched in September 2015. The first six months after the launch would be used for calibrations and verification of performances of the instruments and satellite. It is expected that by April 2016, ASTROSAT would be fully operational.

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108 Md. Shah Alam, **Dipanjan Mukherjee**, Aditya S. Mondal, **Gulab C. Dewangan**, et al. (2015) *XMM-Newton view of a hard X-ray transient IGR J17497-2821* , MNRAS, **451**, 3078.

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114 Jean-Claude Pecker, **Jayant V. Narlikar**, Francois Ochsenbein, and Chandra Wickramasinghe (2015) *The local contribution to the microwave background radiation*, Res. A & A, **15**, 4, 461.

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150 V. V. Klimenko, ..., **R. Srianand**, and D. A. Varshalovich (2015) *Partial covering of the emission regions of Q 0528 - 250 by intervening H_2 clouds*, MNRAS, **448**, 280.

151 S. Muzahid, **R. Srianand**, and J. Charlton (2015) *An HST/COS survey of molecular hydrogen in DLAs and sub-DLAs at z < 1: Molecular fraction and excitation temperature*, MNRAS, **448**, 2840.

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153 **R. Srianand**, **Neeraj Gupta**, E. Momjian, and **M. Vivek** (2015) *Circumnuclear and infalling HI gas in a merging galaxy pair at z=0.123*, MNRAS, **451**, 917.

154 P. Noterdaeme, **R. Srianand**, H. Rahmani, ..., **Neeraj Gupta**, et al. (2015) *VLT/UVES observations of extremely strong intervening damped Lyman-alpha systems: Molecular hydrogen and excited carbon, oxygen, and silicon at log N(HI) = 22.4,* A & A, **577**, 24.

155 **Kandaswamy Subramanian,** and A. Brandenburg (2014) *Traces of large-scale dynamo action in the kinematic stage*, MNRAS, **445**, 2930.

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157 Juie Shetye, **Durgesh Tripathi,** and M. Dikpati (2015) *Observations and modelling of north-south asymmetries using a flux transport dynamo*, Ap. J., **799**, 220.

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159 **M. Vivek**, **R. Srianand**, P. Petitjean, **Vijay Mohan**, et al. (2014) *Variability in low ionization broad absorption line outflows*, MNRAS, **440**, 799.

(b) Proceedings

1 L. Natalucci, and **Varun Bhalerao** (2014) *Decoding the supergiant fast X-ray transient IGR J17544-2619 with NuSTAR,*, 40th COSPAR Scientific Assembly, **40**, 2237.

2 J.A. Tomsick, E. Bellm, ..., **Varun Bhalerao**, et al. (2015) *NuSTAR observations of X-ray binaries*, 10th Integral Workshop [arXiv: 1501.03534].

3 W. Skidmore, I. Dell'Antonio, ..., **Varun Bhalerao**, et al. (2015) *Thirty Meter Telescope: Detailed science case* [arXiv:1505.01195].

4 **Gulab C. Dewangan**, S. Alam, T. Belloni, **Dipanjan Mukherjee**, et al. (2014) *Low frequency QPOs and variable broad iron line from LMC X-1*,The X-ray Universe, Edited by Jan-Uwe Ness,

[http://xmm.esac.esa.int/external/xmm_science/workshops/2014symposium/], id. 62.

5 **Sibasish Laha**, M. Guainazzi, **Gulab C. Dewangan**, ..., and **Ajit Kembhavi** (2014) *Warm absorbers in X-rays (WAX): A comprehensive high resolution grating spectral study of a sample of Seyfert galaxies,*The X-ray Universe, Edited by Jan-Uwe Ness, [http://xmm.esac.esa.int/external/xmm_science/workshops/2014symposium/], id.112.

6 **Dipanjan Mukherjee**, **Dipankar Bhattacharya**, and Andrea Mignone (2014) *Magnetic field structure in accretion columns on HMXB and effects on CRSF*, Physics at the Magnetospheric Boundary, Geneva, Switzerland, Edited by E. Bozzo, et al. EPJ Web of Conferences, **64**, id.02004.

7 **Tarun Souradeep,** Abhay Ashtekar, and Abhay Petkov (2014), *Springer Handbook of Spacetime Chapter 32: Cosmology with the Cosmic Microwave Background*, Edited by Abhay Ashtekar ISBN 978-3-642-41991-1.

8 Kulinder Pal Singh, **S. N. Tandon**, ..., **Dipankar Bhattacharya**, et al. (2014) *ASTROSAT Mission*, SPIE, 9144, id. 91441S, 15.

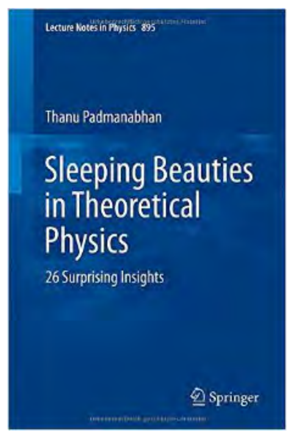
9 J.A. Klimchuk, S. Patsourakos, and **Durgesh Tripathi** (2014) *Intensity conserving spline interpolation (ICSI): A new tool for spectroscopic analysis*, American Geophysical Union, Fall Meeting 2014, Abstract No. SH13B-4109.

(c) Book Authored

T. Padmanabhan

Sleeping Beauties in Theoretical Physics

Springer, Heidelberg (2015)



This book addresses a fascinating set of questions in theoretical physics which will both entertain and enlighten all students, teachers and researchers and other physics aficionados. These range from Newtonian mechanics to quantum field theory and cover several puzzling issues that do not appear in standard textbooks. Some topics cover conceptual conundrums, the solutions to which lead to surprising insights; some correct popular misconceptions in the textbook discussion of certain topics; others illustrate deep connections between apparently unconnected domains of theoretical physics; and a few provide remarkably simple derivations of results which are not often appreciated. The connoisseur of theoretical physics will enjoy a feast of pleasant surprises skilfully prepared by an internationally acclaimed theoretical physicist. Each topic is introduced with proper background discussion and special effort is taken to make the discussion self-contained, clear and comprehensible to anyone with an undergraduate education in physics.
For more details see http://www.iucaa.ernet.in/~paddy/books/sbtp.htm

(d) Book Review

Jayant Narlikar

Yashache nave tatvadnyan (in Marathi) (New philosophy for success), A review of the book 'Chala Ayushya Ghadvuya' by Arvind Pendse and Pratibha Deshpande, Maharashtra Times, September 7, 2014.

PEDAGOGICAL

(a) IUCAA-NCRA Graduate School

Gulab Chand Dewangan : Introduction to Astronomy and Astrophysics I (14 lectures) (August - September 2014)

Ranjeev Misra : Electrodynamics and Radiative Processes I (14 lectures) (August - September 2014)

Kandaswamy Subramanian : Quantum and Statistical Mechanics I (14 lectures) (August - September 2014)

Dipankar Bhattacharya : Quantum and Statistical Mechanics II (14 lectures) (October - December 2014)

Ajit Kembhavi : Introduction to Astronomy and Astrophysics II (14 lectures) (October - December 2014)

T. Padmanabhan : Methods of Mathematical Physics II (14 lectures) (October - December 2014)

R. Srianand : Electrodynamics and Radiative Processes II (14 lectures) (October - December 2014)

Kanak Saha : Galaxies: Structure, Dynamics and Evolution I (21 lectures) (January - February 2015)

Tarun Souradeep : Extragalactic Astronomy I (21 lectures) (January - February 2015)

Neeraj Gupta : Interstellar Medium (14 lectures) (March to May 2015)

(b) S. P. Pune University, M.Sc. (Physics, and Space Science Departments) Lectures

Durgesh Tripathi : Astronomy and Astrophysics I

Aseem Paranjape : Astronomy and Astrophysics II (Cosmology)

Sanjit Mitra : Astronomy and Astrophysics II (General Relativity)

Ranjan Gupta: Laboratory Course (Theory 10 lectures), *Related to Observational Astronomy* (10 laboratory and night experiments)

(c) Supervision of Projects

Dipankar Bhattacharya

Madhuri Gaikwad (S. P. Pune University, MSc Thesis), Magnetic fields from turbulence.

Vishal Kumbhar (S. P. Pune University, MSc Thesis), Magnetic fields from turbulence.

Phalguni Shah (Academy SRFP), Magnetic fields from turbulence.

Umang Sharma (Academy SRFP), Magnetic fields from turbulence.

Arkadip Basak (BITS PS-1 Student), Coded mask imaging with ASTROSAT CZTI.

Anusree K. G. (IUCAA, VSP), Localizing gamma ray sources using a side coding camera.

Gulab Dewangan

Savithri Ezhikkode, DST project on broadband spectral investigation of Active Galactic Nuclei.

Pramod Pawar (SRTM University, Nanded), Collaborative work on optical-x-ray variability of AGN.

Aishwarya A., Possibility of resolving binary supermassive black holes by the Thirty Metre Telescope.

Swechchha Agrawal (Ferguson College, Pune), X-ray spectroscopy.

Neeraj Gupta

Brenda Namumba (University of KwaZulu Natal, South Africa), Evolution of cold gas in active galaxies.

Ayanda Romanis Zungu (University of KwaZulu Natal, South Africa), HI 21 cm absorption as a tracer of cold gas in galaxies.

Poojan Agrawal (IUCAA, VSP), HI in nearby galaxies.
Bhargav Ghanekar (IIT Madras), Reading project on radio astronomy.

Sanjit Mitra
Chaitanya Afle (IISER, Pune), Efficient computation of antenna pattern functions of GW detectors.
Nikhil Mukund Menon (IUCAA), Active noise cancellation in GW detectors.
Saurabh Kumar, (Junior Research Fellow under SERB), Orthogonal bipolar spherial harmonics measures : Scrutinizing sources of isotrophy violation.
Shilpa Kashtha (Visva-Bharati University), Stochastic GW background from a set of gravitationally bound massive bodies.

Jayant Narlikar
Summer School Students' Programme, Foucault Pendulum.

Aseem Paranjape
Shivam Pandey (IIT-Delhi), The role of spatial curvature in generating initial conditions for structure formation (Jointly with Tarun Souradeep, IUCAA).
Mihir Kulkarni (IISER-Pune), Semi-numerical studies of the epoch of reionization, (Jointly with Tirthankar Roy Choudhury, NCRA)
Purnima Narayan (Fergusson College, Pune), The statistical description of galaxy cluster abundances and their dependence on cosmological parameters.
Rhucha Deshpande (IUCAA, VSP), Various aspects of general relativity and cosmology.

Kanak Saha
Pritam Kalbur (S.P. Pune University, M.Sc. thesis), Numerical study of orbits in rotating dark matter halo.
Tanmayee Gupte (S.P. Pune University, M.Sc. thesis), Effect of dynamical friction on Earth's orbit.

Kandaswamy Subramanian
Vaishak Prasad (BITS Pilani), Practice School I.

(d) Supervision of Ph. D. Thesis at IUCAA

Dipankar Bhattacharya
Probing the Evolution of the Magnetic Field of Accreting Neutron Star Binaries
Dipanjan Mukherjee

Ajit Kembhavi
Studies of Warm Absorbers in Active Galactic Nuclei
Sibasish Laha

T. Padmanabhan
Aspects of Quantum Field Theory in Black Holes and Cosmological Spacetimes
Suprit Singh

Tarun Souradeep
Cosmic Microwave Background and the Early Universe
Gaurav Goswami

Tarun Souradeep
Weak Lensing Probes of Cosmology
Aditya Rotti

Kandaswamy Subramanian
The Origin of Large-Scale Magnetic Fields in Galaxies
Luke Chamandy

Kandaswamy Subramanian
Physics of Structure Formation in the Universe
Charles Jose

TALKS

(a) Seminars, Colloquia and Lectures:

Arunima Banerjee

Dark matter halos of spiral galaxies, 6th KIAS Conference on Cosmology and Structure Formation, Seoul, South Korea, November 2014.

Why are some galaxies extremely thin?, Winter School on the Central Region of Spiral Galaxies, IUCAA, Pune, January 2015.

Dark matter halos of spiral galaxies, JESCOL, Department of Physics, St. Xavier's College, Kolkata, February 2015.

Varun Bhalerao

Transients and variables, Workshop on Fabrication of Night Sky Photometer for Small Telescope, IUCAA, September 8, 2014.

NuSTAR observations of X-ray binaries, Hard X-ray Astronomy: ASTROSAT and Beyond, The International Centre, Goa, September 24, 2014.

Compact objects in the time domain with TMT, Conference on Science with the Thirty Metre Telescope, ARIES, Nainital, November 4, 2014.

Seeing what we hear: Electromagnetic counterparts of gravitational wave sources, ARIES, Nainital, November 4, 2014.

SALT studies of binaries, SALT Science Symbosium, IUCAA, Pune, November 17, 2014.

Decoding the SFXT IGRJ17544–2619, Neutron Stars: A Brainstorming Workshop, NCRA, Pune, November 20, 2014.

Observing facilities and time domain activities in India, Remote Presentation in Global Observatories and Discoveries in Time-domain Astronomy and Astrophysics, Singapore, January 9, 2015.

Seeing what we hear: Electromagnetic counterparts of gravitational wave sources, Workshop on Transients, 33rd Meeting of the Astronomical Society of India, February 16, 2015.

ASTROSAT cadmium zinc telluride imager, 33rd Meeting of the Astronomical Society of India, February 17, 2015.

Seeing what we hear: Electromagnetic counterparts of gravitational wave sources, Gravitational Waves Workshop, CMI, Chennai, March 2, 2015.

Seeing what we hear: Electromagnetic counterparts of gravitational wave sources, Colloquium, IISER, Pune, March 25, 2015.

Dipankar Bhattacharya

The ASTROSAT mission, Jyotirvidya Parisanstha, Pune, May 05, 2014.

ASTROSAT, Introductory Summer School in Astronomy and Astrophysics and Vacation Students' Programme, IUCAA, Pune, May 20, 2014.

Observing cyclotron lines with ASTROSAT, ASTROSAT Baseline Science Meeting, IIA, Bengaluru, May 29, 2014.

Magnetar observations with ASTROSAT, ASTROSAT Baseline Science Meeting, IIA, Bengaluru, May 29, 2014.

Rhythm and harmony: C.V. Raman on the Physics of Musical Instrumants, 25th Mid-year Meeting of the Indian Academy of Sciences, IISc, Bengaluru, July 05, 2014.

Explosions in the Universe (2 lectures), Workshop on Recent Trends in Astrophysics and Cosmology, Manipal University, September 04 - 05, 2014.

Virtual observatory - India: Collaborations with South Africa, India-South Africa Science Collaboration Meeting, IUCAA, Pune, September 19, 2014.

Neutron star observations: Mass, radius and magnetic fields, Hard X-ray Astronomy: ASTROSAT and Beyond, Goa, September 25, 2014.

The lure of astronomy: Engineering for a better vision, Online Lecture to BITS, Pilani, October 17, 2014.

Rhythm and harmony: C.V. Raman on the physics of musical instrumants, Leelavati Lecture, IUCAA, Pune, November 5, 2014.

Fast photometry of the LMXB 4U 1626-67 with SALT, SALT Science Symposium, IUCAA, Pune, November 17, 2014.

The physics of neutron stars: Open problems in the SKA era, SKA Neutron Star Workshop, NCRA, Pune, November 20, 2014.

Cyclotron resonance in astrophysics, Colloquium, NCRA, Pune, December 8, 2014.

Cyclotron line science with LAXPC, Workshop on Science with LAXPC/ASTROSAT, December 16, 2014.

Cosmic explosions, Presidency University, Kolkata, February 4, 2015.

Cosmic explosions, St. Xavier's College, Kolkata, February 6, 2015.

Magnetic fields of neutron stars, Second Jesuit Workshop on Observational and Computational Astrophysics, February 6, 2015.

ASTROSAT: India's observatory in space, Nehru Planetarium, Mumbai, Fabruary 8, 2015.

Magnetism of neutron stars, ASI Satellite Workshop on The Magnetic Universe, IUCAA, Pune, February 16, 2015.

An overview of ASTROSAT, 33rd Annual Meeting of the Astronomical Society of India, Pune, February 17, 2015.

Sukanta Bose

Testing Einstein's century old predictions with gravitational waves, Washington State Tri-Cities, November, 2014.

Time-domain astronomy with gravitational waves, NCRA, Pune, February 9, 2015.

What physics and astrophysics of compact objects will gravitational wave observations teach us?, Chennai Mathematical Institute, Silver Jubilee Colloquium, Chennai, March 4, 2015.

Probing strong-gravity phenomena with gravitational waves, IAGRG, RRI, Bengaluru, March 18, 2015.

Sumanta Chakraborty

Black holes: The inside story, Department of Physics, Calcutta University, Kolkata, September 24, 2014.

From dynamical evolution of spacetime to holographic equipartition, Indian Association for the Cultivation of Science, Kolkata, September 25, 2014.

Higher curvature gravity: Extra dimensions and phenomenology, Indian Association for the Cultivation of Science, Kolkata, October 21, 2014.

Evolution of spacetime arises due to the departure from holographic equipartition in all Lanczos-Lovelock theories of gravity, ASI Meeting 2015**,** National Centre for Radio Astrophysics, Pune, February 18, 2015.

A quantum peek inside the black hole event horizon, IUCAA, Pune, March 12, 2015.

Naresh Dadhich

A true constant of spacetime – a new perspective, Workshop on Questioning the Fundamental Principles of Physics, CERN, Geneva, May 6-9, 2014

On pure Lovelock gravity, Institute of Physics, University of Oldenburg, Germany, May 20, 2014.

On pure Lovelock gravity, Deutsches Elektronen-Synchrotron, Hamburg, May 22, 2014.

On pure Lovelock gravity, Albert Einstein Institute, Golm, Germany, June 10, 2014.

On pure Lovelock gravity, Institute of Physics, Silvesian University, Opava, Czech Republic, June 23, 2014.

On pure Lovelock gravity, Institute of Physics, Charles University, Prague, Czech Republic, June 26, 2014.

Magnetic Penrose process: The astrophysical revival of Penrose process, Astronomical Institute, Czech Republic, November 21, 2014.

Gravity in higher dimensions a'la Lovelock, Institute for Theoretical Physics, University of Cologne, Germany, December 2, 2014.

Gulab Dewangan

Soft and hard X-ray excess emission from AGN (NuSTAR results on AGN), Conference on Hard X-ray Astronomy: ASTROSAT and Beyond, Goa, September 24-26, 2014.

Low frequency QPOs and variable broad iron line from LMC X-1, Conference on X-ray Universe 2014, Trinity College, Dublin, Ireland, June 16-19, 2014.

X-ray absorption and reflection in Seyfert galaxies, Winter School on the Central Region of Spiral Galaxies, IUCAA, Pune, January 12-23, 2015.

X-ray variability of AGN, Pt. Ravishankar Shukla University, Raipur, January 29, 2015.

Sanjeev Dhurandhar

Gravitational wave astronomy, IISER, Thiruvananthapuram, July 1, 2014.

Gravitational wave astronomy: Astronomy of the 21st century, IISER, Kolkata, August 21, 2014.

Gravitational wave astronomy: Astronomy of the 21st century, Visva-Bharati University, Santiniketan, February 28, 2015.

Anuradha Gupta

Noise transients in GW detector data: Their modelling and implications, SNU, Seoul, South Korea, July 2015.

Characterization of noise transients in GW detector data and its implications, KISTI, Daejeon, South Korea, June 2015.

Post-Newtonian analysis of preccesing convention for spinning compact binaries, Amaldi11, Gwangju, South Korea, June 2015.

Memory effect from spinning compact binaries in hyperbolic orbits, neutron stars, A Brainstorming Workshop, NCRA, Pune, November 2014.

Life of an astronomer, National Science Day, IUCAA, Pune, February 2015.

Exoplanets: Are we alone in the universe? (in Hindi), National Science Day, IUCAA, Pune, February 2015.

Astronomy: From earth to sun and beyond, New English School, Landewadi, Maharashtra, February 2015.

From Gonda to gravitational wave research: A personal journey, L.B.S.P.G. College, Gonda, December 2014.

Girjesh Gupta

Plasma physics course, IISER, Pune, April 16, 2014.

Exploring the role of waves in the triggering of solar flares and jets, *Indo-German Workshop on Solar Astronomy*, Indian Institute of Astrophysics, Bengaluru, November 17-18, 2014.

Neeraj Gupta

Galaxies in 21cm absorption at z < 3.5, Conference on Galaxies in Absorption, Paris, France, September 22-24, 2014.

MeerKAT absorption line survey, SALT Science Symbosium, IUCAA, Pune, November 17, 2014.

TMT control system, National Conference on Parallel Computing Technologies (PARCOMPTEC 2015), Bengaluru, February 19-20, 2015.

Ranjan Gupta

U-SMART: Small robotic telescopes for universities, APRIM 2014, 12th Asia-Pacific Regional IAU Meeting, Daejeon, Korea, August 18-22, 2014.

Circumstellar dust models for NIR spectra of IRAS objects, Workshop on Current Trends in Near Infrared Astronomy in India, TIFR Balloon Facilty, Hyderabad, November 25-27, 2014.

Modelling of circumstellar dust, IDMC-2014, International Conference on Interstellar Dust, Molecules and Chemistry, Tezpur University, December 15-18, 2014.

Modelling of astrophysical dust and polarimetric observations to constrain these models, Workshop on RoboPol and Polarimetry in Astronomy, IUCAA, Pune, January 6-7, 2015.

Research opportunities in astronomy, National Workshop on Research and Career Opportunities in Astronomy, Gujarat College, Ahmedabad, January 31, 2015.

Ajit Kembhavi

Virtual observatories and large astronomical data collections, Indo-Chile Workshop on BIG Data, Department of Computer Science and Information, BITS, Pilani, Goa, June 5, 2014.

The thirty metre telescope, Cotton College State University, Summer School - 2014, Guwahati, July 4, 2014.

The LIGO-India project, Cotton College State University, Summer School - 2014, Guwahati, July 5, 2014.

Giant telescopes for astronomy, DST INSPIRE Camp, Raipur, August 9, 2014.

Galaxies and AGN I, School on Recent Trends in Astrophysics and Cosmology, Manipal Centre for National Sciences, September 04, 2014.

Galaxies and AGN IIBI, School on Recent Trends in Astrophysics and Cosmology, Manipal Centre for National Sciences, September 04, 2014.

Classical and pseudo bulges: Clues to galaxy formation, Lyon Observatory, France, September 11, 2014.

Classical and pseudo bulges: Clues to galaxy formation, IPA of Grenoble, France, September 18, 2014.

Kepler the astronomer to Kepler the spacecraft' research in astronomy - Opportunities and challenges, Nirmala College, Muvattupuzha, December 9, 2014.

The thirty metre telescope - A giant leap for India, International Conference on Interstellar Dust, Molecules and Chemistry (IDMC 2014), Tezpur University, December 16, 2014.

Mega projects in astronomy, Workshop on Variable Stars and Astronomical Transients, Department of Physics and Astrophysics, University of Delhi (Joint meeting of two IUSSTF Centres), January 15, 2015.

Precision measurements in astronomy, Winter School, VECC, Kolkata, January 27, 2015.

Libraries and the Infonet- Something old and something new, Keynote Address in Inaugural Session: 10th International CALIBER 2015 by INFLIBNET, Shimla, March 12, 2015.

The Universe of light, IRC, M. L. Sukhadia University, Udaipur, March 14, 2015.

Sanjit Mitra

Introduction to cosmic microwave background (1 lecture and 1 hands-on session), Observational Aspects of Astrophysics and Cosmology, Department of Physics, Visva-Bharati University, Santiniketan, November 4, 2014.

Fast GW radiometry using data folding, LIGO-Virgo Collaboration Meeting, Pasadena, USA, March 19, 2015.

Gravitational wave astronomy: Opening new windows to the Universe, IIT Gandhinagar, January 16, 2015.

Gravitational wave astronomy: Opening new windows to the Universe, Akash Mitra, Deccan Gymkhana, Pune, August 16, 2014.

Jayant Narlikar

A case for an alternative cosmology, Perimeter Institute, Canada, May 6, 2014.

A case for an alternative cosmology, Johns Hopkins University, Center for Astrophysical Sciences, Baltimore, USA, May 27, 2014.

Some conceptual problems in GR and cosmology, Perimeter Institute, Canada, June 3, 2014.

Some conceptual problems in general relativity and cosmology, Tata Institute of Fundamental Research, Mumbai, August 27, 2014.

A search for microorganisms in the Earth's atmosphere, United Nations / Austria Symposium on Space Science and the United Nations, Austrian Academy of Sciences, Space Research Institute, Graz, Austria, September 23, 2014.

Naresh, white holes and I, International Conference on Matters of Gravity and the Universe, Centre for Theoretical Physics, Jamia Millia Islamia, New Delhi, October 27, 2014.

Bhaskaracharya II, International Conference on History and Development of Mathematics 2014, Department of Mathematics, Savitribai Phule Pune University, November 27, 2014.

Physics, mathematics and astronomy : A triangular interaction, Department of Mathematics, Savitribai Phule Pune University, February 12, 2015.

Cosmology, Fred Hoyle and I, 33rd Meeting of Astronomical Society of India, IUCAA, Pune, February 17, 2015.

The early days of GR in India, IAGRG 2015 Meeting, Raman Research Institute, Bengaluru, March 18, 2015.

Hamsa Padmanabhan

Probing the Universe: Through reionization and later, 33rd Meeting of the Astronomical Society of India (ASI), National Centre for Radio Astrophysics (NCRA), Pune, February 17 - 20, 2015.

Probing the Universe: Through reionization and later, International Conference on Matters of Gravity and the Universe, Centre for Theoretical Physics, Jamia Millia Islamia, New Delhi, October 27 - 29, 2014.

Probing reionization using quasar near-zones at redshift 6, Science Meeting, ETH Zurich, May 14, 2014.

T. Padmanabhan

The accelerating Universe, Trombay Colloquium, BARC, Mumbai, April 10, 2014.

Cosmic history and mysteries, Infosys, Bengaluru, July 7, 2014.

Cosmic history and mysteries, Infosys Science Foundation and IISc., Bengaluru, July 8, 2014.

Cosmic history and mysteries, Infosys Science Foundation and IISER, Thiruvananthapuram, July 9, 2014.

Cosmic history and mysteries, IUCAA, August 21, 2014.

Cosmic history and mysteries, C.V. Raman Endowment Lecture, Swadeshi Science Congress, Thirur, November 7, 2014.

The enigma of gravity, KSCSTE, Thiruvananthapuram, November 8, 2014.

Emergent gravity paradigm: Recent progress, FTAG Meeting, IISER, Mohali, December 12, 2014.

The enigma of gravity, IISER, Mohali, December 12, 2014.

Gravity and the cosmos, Colloquium, Punjab University, December 17, 2014.

Emergent gravity paradigm: Recent progress, 19th Congress of Philosophy and Foundations of Science, CPFS, Delhi, December 19, 2014.

Cosmic history and mysteries, Nehru Planetarium, Mumbai, December 26, 2014.

Emergent gravity paradigm: Recent progress, Colloquium, IMSc, Chennai, December 29, 2014.

General relativity: The first 100 Years, IISER, Pune, March 23, 2015.

Cosmic history and mysteries, Society for Promotion of Science and Technology in India, (SPTSI), Chandigarh, December 13, 2015.

Aseem Paranjape

Large scale structure and the cosmic web, Radio Astronomy Winter School, IUCAA, Pune, December 2014.

Random walks and large scale structure, Workshop on Statistical Applications to Cosmology and Astrophysics, ISI, Kolkata, February 10 - 13, 2015.

The locations of gravitational collapse: Analytical insights and open issues, IISc, Bengaluru, February 24, 2015.

Krishnamohan Parattu

Quantum mechanics in phase space, Sacred Heart Collage, Thevara, Kerala, December 18, 2014.

Quantum mechanics in phase space, Radio Astronomy Winter School, IUCAA, Pune, December 30, 2014.

Kanak Saha

Secular evolution of galaxies, Workshop on Galaxies and Cosmology, NCRA, Pune, July 2014.

Spin up of classical bulges in barred galaxies, Winter School on the Central Region of Spiral Galaxies, IUCAA, Pune, January 2015.

Is there a classical bulge in our Milky Way?, 33rd Astronomical Society of India Meeting, NCRA, Pune, February 2015.

Is there a classical bulge in the Milky Way?, Galaxies - Celebrating Chanda J. Jog's 60th Birth Anniversary, Indian Institute of Science, Bengaluru, 2014.

Varun Sahni

My life in science, National Science Day, IUCAA, Pune, February 28, 2014.

IAU symposium 308: ***The Zeldovich Universe***, Ya. B. Zeldovich: Chemist, Nuclear Physicist, Cosmologist, Tallinn, Estonia, June 23 - 28, 2014

Old and new ideas in cosmology, Raman Research Institute, Bengaluru, March 18 - 20, 2015.

Sandipan Sengupta

Torsional instantons in quantum gravity, FTAG 2014, IISER, Mohali, December 8 - 13, 2014.

Torsional instantons in quantum gravity, N. R. Sen Award Lecture, IAGRG 2015, RRI, March 18 - 20, 2015

Doing quantum gravity using instantons, Ramakrishna Mission Vivekananda University, Belur, Kolkata, 2015.

Tarun Souradeep

Statistical anisotropies, Primordial Universe after Planck, IAP, Paris, December 15 - 19, 2014.

Planck's cosmos, Plenary talk, IAGRG 2015, RRI, Bengaluru, March 18, 2015.

In pursuit of elusive cosmic gravitational waves, Chennai Mathematical Institute, March 3, 2015.

LIGO-India : An Indian adventure in GW astronomy?, Indian Science Congress, Mega Science Projects in Astronomy, Mumbai, January 4, 2015.

Hints of beyond standard model cosmology, 80th Annual Meeting of the Indian Academy of Sciences, Chennai, November 7-9, 2014.

Observational hints beyond standard model (BSM) cosmology, International Conference on Matters of Gravity and Universe, CTP, Jamia Millia Islamia, New Delhi, October 29, 2014.

The LIGO-India project: An Indian adventure in GW astronomy, APRIM-2014: 12th Asia-Pacific IAU Regional Meeting, Daejeon, South Korea, August 19, 2014.

Hints of BSM cosmology in large angle CMB anisotropy, Cosmology Seminar, APCTP, Pohang, South Korea, August 14, 2014.

Cosmology with CMB: COBE to Planck, Colloquium, Institute of Physics, Bhubaneswar, July 23, 2014.

CMB driven cosmology: Onto the early universe, SERC-THEP School, June 15, 2014.

CMB driven cosmology: The drive so far, CTP, Jamia Millia Islamia, New Delhi, April 23, 2014.

CMB driven cosmology: COBE to BICEP2, Aspects of Cosmology, IIA, Bengaluru, April 9 - 11, 2014.

CMB driven Cosmology: The story thus far, Cosmology Day, ICTS, Bengaluru, April 8, 2014.

R. Srianand

Constraining the fundamental constants using QSO spectra, ESO, Germany, 2014.

Variability of broad absorption line QSOs with SALT, SALT Science Symposium, IUCAA, Pune, 2014.

Galaxy on top of QSOs, Paris, 2014.

Probing the universe with absorption line, Galaxy Workshop, NCRA, Pune, 2014.

Absorption lines as a probe of galaxy evolution, Winter school on the Central Region of Spiral Galaxies, IUCAA Pune, 2015.

Science with TMT, Colloquium, Jamia Millia Islamia, New Delhi, 2015.

K. Subramanian

The origin of cosmic magnetism, NCRA-TIFR Colloquium, Pune, October 2014.

Dynamo models: Where do we stand?, International Conference on Coupling and Dynamics of Solar Atmosphere, IUCAA, Pune, November 2014.

Basics of MHD Pre-ASI Workshop on The Magnetic Universe, IUCAA, Pune, February 2015.

Magnetic field in galaxies and clusters Pre-ASI Workshop on the Magnetic Universe, IUCAA, Pune, February 2015.

Durgesh Tripathi

Science goals of the proposed Indian Solar Space Mission, 12th Asia-Pacific IAU Regional Meeting, South Korea, August 18 - 22, 2014.

Heating of the solar active regions, 12th Asia-Pacific IAU Regional Meeting, South Korea, August 18 - 22, 2014.

Asymmetries in coronal spectral lines and emission measure distribution, International Conference on Coupling and Dynamics of the Solar Atmosphere, IUCAA, Pune, November 10 - 14, 2014.

Solar Ultraviolet Imaging Telescope on board Aditya-L1, Indo-German Workshop on Solar Astronomy, November 17 - 28, 2014.

Solar Ultraviolet Imaging Telescope on board Aditya-L1, 33rd Meeting of the Astronomical Society of India, NCRA, Pune, February 17 - 20, 2015.

Science with Solar Ultraviolet Imaging Telescope on board Aditya-L1 mission, Solar group seminar, Centre for Astrophysics, Smithsonian Astronomical Observatory, Harvard, USA, February 2015.

Nilkanth Vagshette

AGN feedback mechanism of CD galaxy NGC 6338, Conference on Hard X-ray Astronomy: ASTROSAT and Beyond, International Centre, Goa, September 24 - 26, 2014.

Calibration of ASTROSAT CZTI detector, Workshop on Science with LAXPC/ASTROSAT, TIFR Balloon Facility, Hydrabad, December 15 - 17, 2014.

Heating and cooling mechanism in cool core cluster Zwcl 2701, 33rd Meeting of the ASI, NCRA, Pune, February 17 - 20, 2015.

(b) Lecture Courses

Arunima Banerjee

Disk instabilities and the dark matter halo (3 lectures), Introductory Summer School in Astronomy and Astrophysics and Vacation Students' Programme, IUCAA, Pune, May - June 2014.

Dipankar Bhattacharya

Astrophysical fluids and plasmas (4 lectures), Introductory Summer School in Astronomy and Astrophysics and Vacation Students' Programme, IUCAA, Pune, May 5 - 7 and May 28, 2014.

Gulab Dewangan

X-ray astronomy and active galactic nuclei (4 lectures), Introductory Summer School in Astronomy and Astrophysics and Vacation Students' Programme, IUCAA, Pune, May - June, 2014.

Sanjeev Dhurandhar

Gravitational wave data analysis (5 lectures), IISER Thiruvananthapuram, June 23 - July 04, 2014.

Gravitational wave data analysis (4 lectures), IISER, Thiruvananthapuram, August 19 - 23, 2014.

Fourier transforms and their applications (4 lectures), Statistics Department, Kolkata University, February 23 - 27, 2015.

Ranjan Gupta

Basics of astronomy (4 lectures), IMD-CTI, Pune, January 8-9, 2014

Stellar spectroscopy (2 lectures), Introductory Summer School in Astronomy and Astrophysics and Vacation Students' Programme, IUCAA, Pune, May 5 - June 6, 2014.

Sanjit Mitra

Introduction to cosmic microwave background (2 lectures), Workshop on Recent Developments in Cosmology, Kochi, September 11, 2014.

Introduction to gravitational wave astronomy and cosmic microwave background (2 lectures), IUCAA-MCNS Workshop, Manipal, September 5 - 6, 2014.

Jayant Narlikar

Cosmology (5 lectures), Centre for Excellence in Basic Sciences, University of Mumbai, April 9 - 17, 2014.

Action at a distance electrodynamics (6 lectures), IUCAA, Pune, October 14 - 30, 2014.

T. Padmanabhan

Special and general relativity (4 lectures), Introductory Summer School in Astronomy and Astrophysics and Vacation Student's Programme, IUCAA, Pune, May - June, 2014.

Aseem Paranjape

Structure formation (4 lectures), Workshop on Cosmology with Large Scale Structures, Jamia Millia Islamia, New Delhi, January 5 - 9, 2015.

Kanak Saha

Basics of galaxies (3 lectures), Winter School on the Central Region of Spiral Galaxies, IUCAA, Pune, January 12 - 23, 2015.

Galaxy dynamics and evolution (4 lectures), Introductory Summer School in Astronomy and Astrophysics and Vacation Students' Programme, IUCAA, Pune, May - June, 2014.

Galaxies - I & II (2 lectures), Radio Astronomy Winter School, IUCAA-NCRA, Pune, December 2014.

R. Srianand

Electrodynamics - II : AGNs and IGM (4 lectures), Introductory Summer School in Astronomy and Astrophysics and Vacation Students' Programme, IUCAA, Pune, May-June 2014.

Observational probes of structures (5 lectures), Workshop on Cosmology with Large Scale Structure, Jamia Millia Islamia, New Delhi, January 2015.

Galaxies and observational cosmology (5 lectures), Venkateswara College, New Delhi, 2014.

Spectroscopy workshop, (3 lectures + Demo), Kerala Academy of Sciences.

Introduction to spectroscopy (4 lectures) + How to write proposals, IGO-School, IUCAA, Pune.

K. Subramanian

Cosmic magnetic fields (3 lectures), and ***Structure formation in the Universe*** (1 lecture), Introductory Summer School in Astronomy and Astrophysics and Vacation Students' Programme, IUCAA, Pune, May 2014.

Cosmology and structure formation (2 lectures), Venkateswara College, New Delhi, September 2014.

Magnetic fields in galaxies (3 Lectures), Workshop on Galaxies and Cosmology, NCRA-TIFR, Pune, July 2014.

Structure formation in the Universe (4 lectures), Workshop on Cosmology with Large Scale Structure, CTP, Jamia Millia Islamia, New Delhi, January 2015.

Durgesh Tripathi

Basics of solar astrophysics (3 lectures), Workshop on Solar Astrophysics, Providence Women's College, Calicut and Regional Science Centre and Planetarium, Calicut, January 19 - 20, 2015.

INTRODUCTORY SUMMER SCHOOL IN ASTRONOMY AND ASTROPHYSICS (for College/University Students)

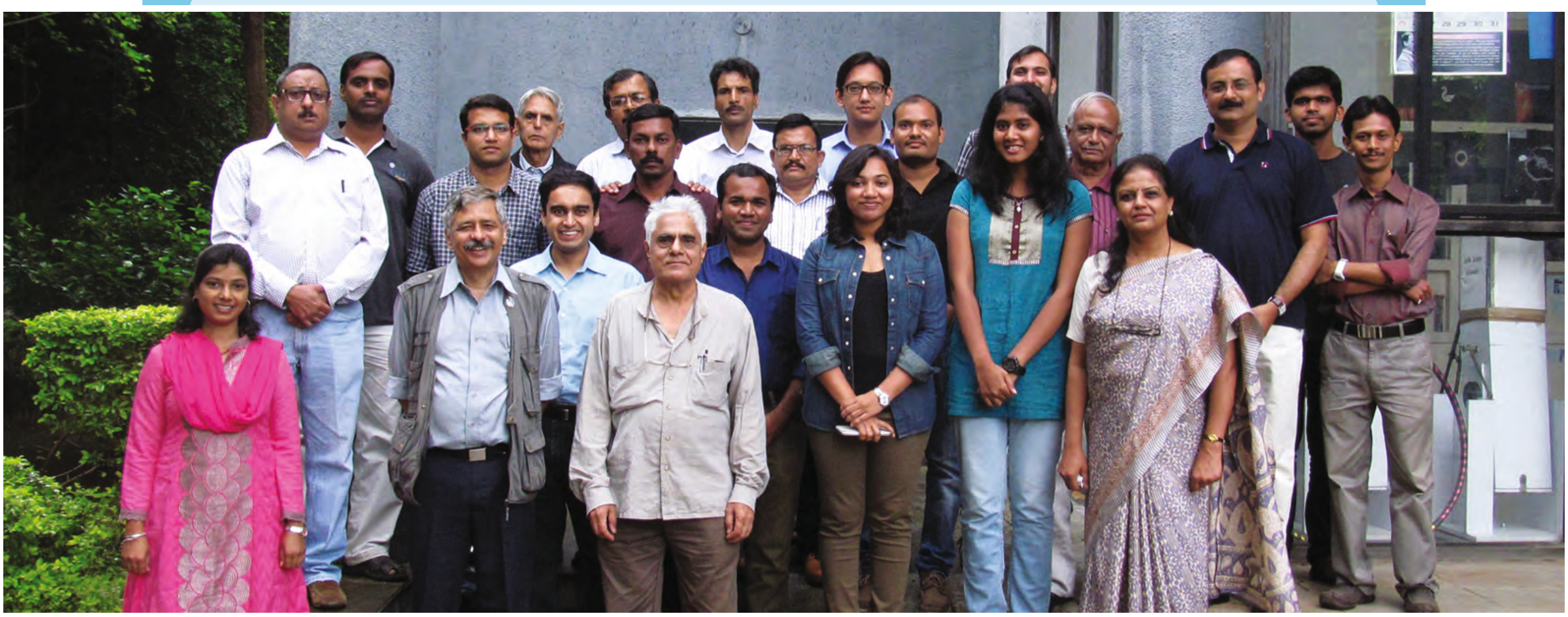
Introductory Summer School in Astronomy and Astrophysics was conducted at IUCAA during May 5 - June 6, 2014.

[For details see Khagol, Issue No. 99, July 2014]

INDIA - SOUTH AFRICA FLAGSHIP MEETING

India-South Africa Flagship Meeting was organised at IUCAA, on September 19, 2014.
The wprkshop was coordinated by Nithaya Chetty from South Africa and Ranjan Gupta.
[For details see Khagol, issue No. 100, October 2014]

WORKSHOP ON FABRICATION OF NIGHT SKY PHOTOMETER FOR SMALL TELESCOPES



Workshop on Fabrication of Night Sky Photometer for
Small Telescopes was organised during September 8-12, 2014.
[For details see Khagol, issue No. 100, October 2014]

IUCAA FOUNDATION DAY SILVER JUBILEE LECTURE

IUCAA Foundation Day Silver Jubilee Lecture was delivered by Abhay Ashtekar on December 29, 2014.

[For details see Khagol, issue No. 101, January 2015]

INTERNATIONAL CONFERANCE ON COUPLING AND DYNAMICS OF THE SOLAR ATMOSPHERE

International Conference on Coupling and Dynamics of the Solar Atmosphere was organised at IUCAA in the Chandrasekhar Auditorium during November 10-14, 2014.

[For details see Khagol, issue No. 101, January 2015]

WINTER SCHOOL ON THE CENTRAL REGION OF SPIRAL GALAXIES

Winter School on the Central Region of Spiral Galaxies was organised at IUCAA during January 12-23, 2015.

[For details see Khagol, issue No. 102, April 2015]

WORKSHOP ON ROBOPOL AND POLARIMETRY IN ASTRONOMY

Workshop on RoboPol and Polarimetry in Astronomy was conducted at IUCAA during January 6-7, 2015

[For details see Khagol, issue No. 102, April 2015]

Ph.D. PROGRAMME

Seven IUCAA Research Scholars have defended their Ph.D. theses, namely: **Luke Chamandy** (Guide: Kandaswamy Subramanian), **Gaurav Goswami** (Guide: Tarun Souradeep), **Charles Jose** (Guide: Kandaswamy Subramanian), **Sibasish Laha** (Guide: Ajit Kembhavi), **Dipanjan Mukherjee** (Guide: Dipankar Bhattacharya) , **Aditya Rotti** (Guide: Tarun Souradeep), and **Suprit Singh** (Guide: T. Padmanabhan). 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 :

The Origin of Large-Scale Magnetic Fields in Galaxies

Luke Chamandy

Magnetic fields are an important component of spiral galaxies, and hence, it is necessary to understand their origin, structure and evolution. In this thesis, we present models that describe the growth, saturation and physical properties of large-scale galactic magnetic fields. This is done by taking into account the non-linear back-reaction of the magnetic field on the turbulence, and hence, on the dynamo action. The primary focus of the thesis is to explain the origin and observed characteristics of the non-axisymmetric components of large-scale magnetic fields in galaxies. Along the way, we develop and analyse various tools of non-linear galactic dynamo theory, and incorporate a number of physical effects into the theory for the first time.

We begin by comparing different models and approximations for non-linear mean field dynamos in disc galaxies to assess their applicability and accuracy, and thus, to suggest a set of simple solutions suitable to model the large-scale galactic magnetic fields in various contexts. The dynamo saturation mechanisms considered are the magnetic helicity balance involving helicity fluxes (the dynamical α-quenching and an algebraic α-quenching). The non-linear solutions are then compared with the marginal kinematic and asymptotic solutions. We also discuss the accuracy of the no-z approximation. Although, these tools are very different in degree of approximation and hence complexity, they all lead to remarkably similar solutions for the mean magnetic field. In particular, we show that the algebraic α-quenching non-linearity can be obtained from a more physical dynamical α-quenching model in the limit of nearly azimuthal magnetic field. This suggests, for instance, that earlier results on galactic disc dynamos based on the simple algebraic non-linearity are likely to be reliable, and that estimates based on simple, even linear models are often a good starting point. We suggest improved no-z and algebraic α-quenching models, and also incorporate galactic outflows into a simple analytical dynamo model to show that the outflow can produce leading magnetic spirals near the disc surface. The simple dynamo models developed are applied to estimate the magnetic pitch angle and the arm-inter-arm contrast in the saturated magnetic field strength for realistic parameter values.

More refined and detailed global dynamo models are then developed to investigate various properties of galactic large-scale magnetic fields. The effect of the dynamical α-quenching on the magnetic field evolution in an axisymmetric disc galaxy is explored. We confirm the work of earlier models based on the algebraic α-quenching formalism, in that sufficiently strong random seed fields can lead to global reversals of the large-scale field along the radius whose long-term survival depends on specific features of a given galaxy. Within this general framework, coherent large-scale magnetic spiral arms superimposed on the dominant axially symmetric magnetic structure are then considered.

We first show that such non-axisymmetric components tend to decay in the non-linear regime in a disc that lacks non-axisymmetric forcing of the dynamo. We find, however, that the enhancement of the kinetic α effect (α_k) in spiral shaped regions (which may overlap the gaseous spiral arms or be located in the inter-arm regions) can lead to strong non-axisymmetry, in the form of spiral shaped regions of enhanced large-scale magnetic field. A non-axisymmetric forcing of the mean-field dynamo by a spiral pattern (either stationary or transient) is invoked. For a stationary dynamo forcing by a rigidly rotating α_k-spiral, we find co-rotating non-axisymmetric magnetic modes enslaved to the axisymmetric modes and strongly peaked around the co-rotation radius. At all galacto-centric distances, except for the co-rotation radius, we find magnetic arms displaced in azimuth from the α_k-arms, so that the ridges of magnetic field strength are more tightly wound than the α_k-arms. For a forcing by transient gaseous material, arms wound up by the galactic differential rotation, the magnetic spiral is able to adjust to the winding so that it resembles the gaseous spiral at all times.

Famously, magnetic arms have in some cases been observed between the gaseous arms of some spiral galaxies; the origin of these phase-shifted magnetic arms remains unclear. With this motivation, we generalise the theory of mean-field galactic dynamos by allowing for temporal non-locality in the mean electromotive force (emf). This arises in random flows due to a finite response time of the mean emf to changes in the mean magnetic field and small-scale turbulence, and leads to the telegraph equation for the mean field. There are profound effects associated with the temporal non-locality, i.e., finite 'dynamo relaxation time'. For the case of a rigidly rotating spiral, a finite relaxation time causes each magnetic arm to mostly lag the corresponding gaseous arm with respect to the rotation. For a transient α_k spiral that winds up, the finite dynamo relaxation time leads to a large, negative (in the sense of the rotation) phase shift between the magnetic and α_k arms, similar to the phase shift between magnetic and gaseous arms observed in NGC 6946 and other galaxies.

The exploration of mean-field galactic dynamos affected by a galactic spiral pattern is then continued with an asymptotic solution. As with the numerical solutions, the mean-field dynamo model generalizes the standard theory to include the delayed response of the mean electromotive force to variations of the mean magnetic field and turbulence parameters (the temporal non-locality, or τ effect). The axisymmetric and enslaved non-axisymmetric modes of the mean magnetic field are studied semi-analytically to clarify and strengthen the numerical results. Good qualitative agreement is obtained between the asymptotic solution and numerical solutions for a global, rigidly rotating α_k-spiral (density wave).

Steady rigidly rotating spirals and transient spirals which co-rotate with the gas at every radius are attractively simple, albeit not completely realistic, models for the morphology and evolution of the gaseous spiral which forces the dynamo. Thus, we investigate the effects of more realistic spiral models. Interfering two- and three-arm spiral patterns have previously been inferred to exist in many galaxies and also in numerical simulations, and invoked to explain important dynamical properties, such as lack of symmetry, kinks in spiral arms, and star formation in armlets. We, therefore, generalize our non-axisymmetric galactic mean-field dynamo model to allow for such multiple co-existing spiral patterns in the kinetic α_k effect, leading to the existence of magnetic spiral arms in the large-scale magnetic field with several new properties. The large-scale magnetic field produced by an evolving superposition of two- and three-arm (or two- and four-arm) patterns evolves with time along with the superposition. Magnetic arms can be stronger and more extended in radius and in azimuth when produced by two interfering patterns rather than by one pattern acting alone. Transient morphological features arise in the magnetic arms, including bifurcations, disconnected armlets, and temporal and spatial variation in arm strength and pitch angles. Pitch angles of the large-scale magnetic field and magnetic arm structures (ridges) are smaller than those typically inferred from observations of spiral galaxies for some model parameters, but can become comparable to typically inferred values for certain (still realistic) parameters. The magnetic field is sometimes strongest in between the α_k-arms, unlike in standard models with a single pattern, where it is strongest within the α_k-arms. Moreover, for models with a two- and three-arm pattern, some amount of $m = 1$ azimuthal symmetry is found to be present in the magnetic field, which is generally not the case for forcing by single two- or three-arm patterns. Many of these results are reminiscent of observed features in the regular magnetic fields of nearby spiral galaxies, like NGC 6946, which has previously been inferred to have significant two- and three-arm spiral patterns, and IC 342, which has been reported to contain an inner two-arm and outer four-arm pattern.

As with the nature of the spiral model forcing the dynamo, the mechanism of the non-axisymmetric forcing itself can be modelled in various, more or less realistic, ways. Spiral modulation of the α_k effect is certainly plausible, though not directly observable. We, therefore, explore a mechanism of non-axisymmeteric forcing that is physically better motivated, namely the concentration of outflows in the gaseous arms (and their suppression in the interarm regions). We find that magnetic spiral arms can be naturally generated in the inter-arm regions of some galaxies since the galactic fountain flow or wind, driven by star formation, hinders the large-scale dynamo action and thus, the large-scale magnetic field in the gaseous arms. Moreover, in addition to the interfering spiral pattern model, we explore the effects of an evolving linear density wave model. For both spiral models, we find strong inter-arm magnetic arms for an outflow that is sufficiently large (though not so large as to render the dynamo sub-critical). Magnetic arms are rendered stronger when the τ effect is included in the model. Moreover, magnetic arms in the evolving density wave model are radially extended with arm pitch angles similar to those of the $\overline{U}_z$ (gaseous) arms, i.e., the type of interlacing magnetic arms seen in NGC 6946.

In summary, the thesis explores the implications of various physical effects, from dynamical non-linearities to temporal non-locality to spiral arm evolution to galactic outflows, on large-scale galactic dynamos.

Cosmic Microwave Background and the Early Universe

Gaurav Goswami

In the recent past, physical cosmology has rapidly advanced due to much better observations of the universe. This has helped in understanding the physical principles governing the Universe much better. In particular, the observations of the anisotropies of the Cosmic Microwave Background (CMB) seem to support the inflationary paradigm. In this thesis, we address the following issues about the inflationary paradigm:

(i) *Deconvolution of the amplitude and shape of scalar Primordial Power Spectrum (PPS) using CMB observations:* We introduce the Maximum Entropy Method, a new attempt to probe the amplitude and shape of the PPS and apply it to binned angular power spectrum data of CMB anisotropies obtained by WMAP experiment.

(ii) *The effect of the dynamics of background spacetime on the generated PPS:* We explore a class of inflationary scenarios in which inflation either briefly gets interrupted or briefly transits to a phase of fast roll. We find that linear perturbation theory implies that in such scenarios, the PPS has sharp features and that, it is possible to construct inflationary models in which this necessarily leads to some scales ending up with no fluctuation as they eventually become super-Hubble.

(iii) *Renormalization in cosmological perturbation theory:* Working with a specific regime of the effective field theory of inflation, we look at subtleties associated with renormalization of cosmological correlators and find the crucial ways in which this calculation of renormalization differs from the one performed in more familiar applications of Quantum Field Theory.

Physics of Structure Formation in the Universe

Charles Jose

Understanding the formation and evolution of galaxies at high redshifts is an important issue in physical cosmology. In this thesis, we present a physically motivated galaxy formation model in the framework of Lambda cold dark matter (ΛCDM) cosmology to understand the evolution of high-z galaxies in the redshift range 3 to 8 along with their luminosity functions (LF). We use the available observations to constrain the parameters of the model. We then use this model to place strong constraints on neutrino mass. Our galaxy formation model is further combined with the halo model of large scale structures to probe the spatial clustering of Lyman break galaxies (LBGs) and Lyman-α emitters (LAEs). We also have investigated the clustering statistics of high-z dark matter halos using N-body simulations to understand the discrepancy between LBG correlation functions predicted using halo model and that obtained from observations.

We begin by presenting our galaxy formation model to understand the evolution of stellar mass (M_*) - UV luminosity relations, stellar mass functions and specific star formation rate (sSFR) of LBGs along with their UV LFs in the redshift range $3 \leq z \leq 8$. Our model assumes a physically motivated form for the star formation history in a galaxy and the model parameters are calibrated by fitting the observed UV LFs of LBGs. Our main findings are as follows: The fraction of baryons that gets converted into stars remain nearly constant for $z \geq 4$, but shows an increase for $z < 4$. However, the rate of converting baryons into stars do not evolve significantly in the redshift range $3 \leq z \leq 8$. This model further successfully explains the M_* - UV luminosity correlations of LBGs. While our model predictions of stellar mass functions compare well with the inferred data from observations at the low mass end, we need to invoke the Eddington bias to fit the high mass end. We find that at any given redshift, the sSFR to remain constant over the stellar mass range $5 \times 10^8 - 5 \times 10^9 M_\odot$ and the redshift evolution of sSFR is well approximated by a form $(1+z)^{2.4}$ for $3 \leq z \leq 8$, which is consistent with observations. Thus, we find that dark matter halo build up in the ΛCDM model is sufficient to explain the evolution of UV LFs of LBGs along with their M_* - UV luminosity relations, the stellar mass functions and the sSFR for $3 \leq z \leq 8$.

We then demonstrate that the UV LFs of high-z LBGs can be used to place stringent constraints on the neutrino mass. Laboratory experiments measuring neutrino oscillations, indicate small mass differences between different mass eigenstates of neutrinos. The absolute mass scale is, however, not determined with the strongest upper limits at present coming from astronomical observations rather than terrestrial experiments. The presence of massive neutrinos suppresses the growth of perturbations below a characteristic mass scale, thereby leading to a decreased abundance of collapsed dark matter halos. We show that this effect can significantly alter the predicted shape of LFs of high-z LBGs, which can be used to place limits on neutrino mass. Combining the constraints from the Wilkinson Microwave Anisotropy Probe (WMAP) 7 year data with the LF data of LBGs at $z \sim 4$, we get a limit on the sum of the masses of 3 degenerate neutrinos $\Sigma m_\nu < 0.52$ eV at the 95 % CL. The additional constraints using the prior on Hubble constant strengthens this limit to $\Sigma m_\nu \leq 0.29$ eV at the 95 % CL. This neutrino mass limit is a factor ~ 4 improvement compared to the constraint based on the WMAP7 data alone, and as stringent as known limits based on other astronomical observations. As different astronomical measurements may suffer from different set of biases, the method presented here provides a complementary probe of Σm_ν. We suggest that repeating this exercise on well measured LFs over different redshift ranges can provide independent and tighter constraints on Σm_ν.

We next combine our galaxy formation model with the halo model of large scale structures to understand the clustering of high-z LBGs. First using dark matter halo bias, we predict the large scale (i.e ., $\theta \geq 80''$) galaxy bias and the angular correlation functions of central LBGs, which compare remarkably well with the observations. We then incorporate satellite galaxies into our model using the conditional mass function and our star formation model. Thus, we compute the halo occupation distribution (HOD) of LBGs using our galaxy formation model without assuming any functional form. The halo model using this HOD is shown to provide a reasonably good fit to the observed clustering of LBGs at both large ($\theta > 80''$) and small ($\theta < 10''$) angular scales for the whole range of $z = 3 - 5$ and limiting magnitudes. However, our models underpredict the clustering amplitude at intermediate angular scales, where quasi-linear effects are important. Our physical model for the HOD suggests that, for a limiting absolute magnitude of -20.5 at $z = 4$, the average mass of halos contributing to the observed clustering is 6.2×10^{11} $M_\odot$. The characteristic mass of a parent halo hosting satellite galaxies of similar brightness is 1.2×10^{12} $M_\odot$. For a given threshold luminosity, these masses decrease with increasing z, and at any given z these are found to increase with increasing value of threshold luminosity. We also find that approximately 40% of the halos above a minimum mass M_{min}, can host detectable central galaxies and about $5 - 10$% of these halos are likely to also host a detectable satellite. These satellites form typically a dynamical time-scale prior to the formation of the parent halo. The small angular scale clustering is mainly due to central-satellite pairs rather than a few large clusters. It is quite sensitive to changes in the duration of star formation in a halo with the present data favouring star formation in a dark matter halo lasting typically for a few dynamical time-scales.

Our model for the clustering of LBGs is then extended to also explain that of high-z LAEs. The model parameters are constrained by the observed LFs of LAEs and are further used to predict their large scale bias and angular correlation function. These predictions are shown to reproduce the observations remarkably well. We find that the average mass of dark matter halos hosting LAEs brighter than a threshold narrow band magnitude of ~ 25 is $\sim 10^{11} M_\odot$. This is smaller than that of typical LBGs brighter than similar threshold continuum magnitude by a factor ~ 10. This results in a smaller clustering strength of LAEs compared to LBGs. However, using the observed relationship between UV continuum and Lyman-α line luminosity of LAEs, we show that both LAEs and LBGs belong to the same parent galaxy population with narrow band techniques having greater efficiency in picking up galaxies with low UV luminosity. We also show that the lack of evidence for the presence of the 1-halo term in the observed LAE angular correlation functions can be attributed to the sub-Poisson distribution of LAEs in dark matter halos as a result of their low halo occupations.

The clustering amplitude of brighter samples of LBGs at intermediate angular scales ($10'' \leq \theta \leq 80''$) is systematically underpredicted in our models. This suggests that the linear bias approximation is not sufficient to explain the clustering of high-z dark matter halos on scales bigger than their typical virial radii. We have investigated this by directly measuring the halo correlation functions from N-body simulations at redshifts $z \geq 3$. A comparison of the halo correlation functions measured directly from simulations with that predicted analytically show that the effect of non-linear bias is quite significant on quasi-linear scales ($1-10$ Mpc/h) at high redshifts. Our studies, using simulations, also suggest that the non-linear bias of a halo of mass M at any length scale (r) is a function of only two parameters, the rms density fluctuations at that mass and dark matter correlation functions at that length scale. Motivated by this, we provide an analytic fitting formula for the non-linear bias as a function of these two parameters. We further show that, for $z \geq 3$, non-linear bias significantly reshapes LBG correlation functions on scales $10'' \leq \theta \leq 80''$, providing very good agreement with observed data.

Studies of Warm Absorbers in Active Galactic Nuclei

Sibasish Laha

The soft X-ray spectra of nearly half of all nearby Seyfert 1 galaxies show signatures of warm absorbers (WA) in the form of absorption lines and edges. These features are sensitive diagnostics of the ionisation parameter and the kinematics of the absorbing gas, which are important for studying AGN structure and feedback to galaxies. This thesis aims at characterising the properties of warm absorbing gas in a well defined, flux-limited sample of nearby AGN.

The WAX (warm absorbers in X-rays) sample was selected as a sub-sample of the CAIXA (Catalogue of AGN in XMM Archive) sample. We have cross-correlated the CAIXA sources with the RXTE X-ray Sky Survey (XSS), and retained only those sources with an XSS 38 keV count rate $\geq 1\mathrm{s}^{-1}$. The final sample of WAX has 26 sources and it is $\sim 76\%$ complete with respect to RXTE/XSS sources with a count rate > 1 count s^{-1}. In the sample study, we have made use of data obtained with the XMM-Newton satellite.

We detect with high significance WAs in 65% of the sample sources. Taking into account the data statistical quality, and the coverage of the parent sample, our results are consistent with WAs being present in $\sim 90\%$ of nearby, X-ray bright Seyferts. We have put a strict lower limit on the detection fraction of $\sim 50\%$, which indicates that at least half of all the Seyfert galaxies in the nearby Universe exhibit warm ionised outflows, in agreement with previous estimates. We find a gap in the distribution of the ionisation parameter in the range $0.5 < \log \xi < 1.5$, which we interpret as a thermally unstable region for WA clouds. This may indicate that the warm absorber flow is probably constituted by a clumpy distribution of discrete clouds rather than a continuous medium. The distribution of the WA column density for the sources with broad Fe K lines are similar to those sources which do not have broadened emission lines. Therefore, the detected broad Fe Kα emission lines are bonafide and not artefacts of ionised absorption in the soft X-rays. The WA parameters show no correlation among themselves, with the exception of the ionisation parameter versus column density. The shallow slope of the $\log \xi$ versus $\log(v_{\mathrm{out}})$ linear regression (0.12 ± 0.03) is inconsistent with the scaling laws predicted by radiation or magneto-hydrodynamic-driven winds. Our results suggest also that WA and Ultra Fast Outflows (UFOs) do not represent extreme manifestation of the same astrophysical system.

From a case study of a bright narrow line Seyfert galaxy IRAS 13349+2438, we have found that the ionizing continua with different shapes create different ionisation structures in WA clouds for the same ionisation parameter and column density of the cloud. The best-fit WA parameters obtained using WA models generated with different input ionizing continua for the Seyfert 1 galaxy IRAS 13349+2438 are different. Hence, determining the accurate shape of the ionising continuum over the entire effective energy range becomes necessary for generating the WA models, which is, however, not possible due to the galactic extinction in the range 13.6 - 300 eV. The only way out is to characterise the big-blue-bump (BBB) and the soft- excess (SE) with physical models, and extrapolate them into the unobserved region of the spectral energy distribution (SED). We have developed realistic continua based on multi-wavelength observations, which consists of the SE and a power-law emission in the X-rays and the BBB in the UV. We have found that the different physical models for SE (blurred Compton reflection and optically thick thermal Comptonisation) predict different fluxes in the unobserved energy range, but the current X-ray data quality does not allow us to distinguish between them using derived WA parameters. The extent of stable regions in the stability curves is large for the realistic continuum, which possibly indicates a continuous distribution of the WA gas for this source.

The orientation of some AGNs is intermediate between the orientation of Seyfert 1 and 2 galaxies relative to the observer. That is, they are viewed with an inclination comparable with the "torus opening angle", hence the line of sight to the nucleus passes through the upper layers of the torus. The emission from the central engine, therefore, suffers only a moderate extinction through the torus rim (Smith et al., 2002), and their polarised spectra are dominated by polar scattering. Such an AGN is called a polar scattered Seyfert 1 (PSS) galaxy. We have performed a detailed analysis of a long XMM-Newton observation of the PSS galaxy MRK 704. We have detected the presence of a partially covering cold absorber intrinsic to the source. The high column density ($\mathrm{N_H} = 10^{23}\,\mathrm{cm^{-2}}$) of the cold absorber supports the assumption that MRK 704 is a polar scattered Seyfert galaxy and we are looking at the source along a line of sight that grazes the torus. A broad FeKα line is detected at 6.4 keV with v_{FWHM} 11,000 $\mathrm{km\,s^{-1}}$. The line can arise either from the inner broad line region or the outer regions of the accretion disk. A two phase warm absorber with $\log\xi = 1.27$ and $\log\xi = 2.7$ are detected in the spectrum. The lower ionisation phase has a faster outflow velocity $\sim 1,350\,\mathrm{km\,s^{-1}}$, while the higher ionisation phase has a lower velocity $\sim 450\,km\,s^{-1}$. Weak emission features of He-like triplets of O VII and N VI are identified. One of the lines in the triplets is in much faster outflow ($\sim 5,000\,\mathrm{km\,s^{-1}}$) than the other two lines, which are from a cloud with outflow velocity consistent with zero. The CLOUDY modelling points out to two possible situations. The first is that there are two sets of clouds with different velocities and different densities ($\mathrm{n_e} = 10^9$ and $10^{13}\,\mathrm{cm^3}$). The higher density, higher outflow velocity cloud produces the resonant line, while the lower density lower velocity cloud gives rise to the inter-combination and forbidden lines. The second situation is that there are two clouds of low density ($\mathrm{n_e} = 10^9\,\mathrm{cm^3}$) but with different outflow velocities giving only inter-combination and forbidden lines. The low density emission phase is likely similar to the X-ray narrow-line region observed from many Seyfert 2 galaxies. The high velocity, outflowing emission phase is unique to MRK 704.

Probing the Evolution of the Magnetic Field of Accreting Neutron Star Binaries

Dipanjan Mukherjee

Accreting neutron stars can be broadly classified as high field pulsars with surface fields $\sim 10^{12}$ G, and low field pulsars with surface fields $\sim 10^8$ G. It is generally believed that continued accretion over a long duration results in the decrease of the surface field strength of the pulsar from an initial value of $\sim 10^{12}$ G at birth. One of the proposed mechanisms of field reduction is by a burial of the field by accreted matter. In this scenario, the local magnetic field is distorted by equator-ward spreading of accumulated matter, forming current sheets which screen the dipole field. However, magnetohydrodynamic and plasma instabilities can limit the efficiency of the confinement process, causing cross field diffusion and outflow of mass from the accretion mound. We aim to study such confinement, starting with the evaluation of the magnetic field and density distribution in a mound in static equilibrium. Subsequently, we perturb the obtained equilibrium solutions using 2D and 3D MHD simulations to investigate the presence of unstable modes.

In Chapter 1, we present the estimates of field strengths of accreting millisecond X-ray pulsars (AMXPs) obtained by analysis of archival *RXTE/PCA* data. We have employed the indirect method of field estimation outlined by Psaltis and Chakrabarty, which constrains the magnetic field strength by assuming that the magnetically limited inner edge of the accretion disk lies inside the co-rotation radius when pulsed emission is seen. This work involves a search for pulsations in the archival *RXTE* data over the entire outburst history of all AMXPs. From the observations with confirmed detection of pulsations, a measure of bolometric source luminosity has been obtained using X-ray spectral analysis for the highest and the lowest flux states. These estimates have been used to derive constraints on the possible range of the surface dipole magnetic field strength of the AMXPs.

In accreting neutron stars, infalling matter accumulates at the magnetic pole of the neutron star, confined by the magnetic field. In Chapter 2, we present the solutions of the the static Euler equation modelling such an accretion mound. We numerically solve the Grad-Shafranov equation to evaluate the density and magnetic field structure of the mound in force equilibrium. We have obtained solutions for mounds of different shapes and several choices of equation of state of the plasma. We have performed the computations in cylindrical coordinates for mounds confined to a polar cap of radius 1 km. For more extended polar caps, we have obtained the solutions in spherical coordinates, and found a threshold mound size beyond which converged solutions are not obtained by the numerical technique used. For mounds larger than the threshold, closed magnetic loops are formed inside the computation domain, leading to loss of equilibrium. Such a threshold size is indicative of the onset of MHD instabilities.

In Chapter 3, we discuss the 2D axisymmetric simulations performed to analyse the stability of the Grad-Shafranov (GS) solutions. We perturb the equilibrium solutions imported from the GS solver into the PLUTO MHD code and follow their evolution guided by the full set of MHD equations. We find that instabilities are triggered when the excess mass, added as a perturbation, descends due to gravity. The mounds near the GS threshold obtained from the static solutions are found to be spontaneously unstable with instabilities being triggered with perturbations of weak strength. The descending matter results in the formation of closed magnetic loops and the system does not relax to a new equilibrium solution. Although gravity driven modes are triggered by the addition of excess mass, interchange modes are not found to be excited in the 2D simulations.

The onset of interchange and ballooning modes are investigated in 3D simulations described in Chapter 4. We import the initial 2D axisymmetric solution from the GS equation and rotate it in the azimuthal direction to create the initial 3D set up. We apply random velocity perturbations throughout the domain at the start of the simulation and evolve the system for several Alfvén times. We find that the onset of MHD instabilities results in the formation of multiple radial streams distributed across the azimuthal direction, destroying the initial axisymmetry. The density is found to settle in magnetic valleys, resulting in outward radial flows. We have found a threshold mound size beyond which instabilities are triggered.

X-ray emission from an accreting neutron star may be affected by the distortion of its strong field due to the pressure of the accreted matter. A direct tracer of the local magnetic field in an emission region is the set of cyclotron resonance scattering features (CRSF) that appear as absorption dips in the X-ray spectra. In Chapter 5, we compute and predict the CRSF spectrum from the top layer of the accretion mounds represented by the equilibrium solutions derived from our GS equation. We find that the emission integrated from the mound surface will result in asymmetric CRSF with complex line shapes. Sharp variations in the magnetic field on the mound result in multiple dip-like features in the spectra, which can be detected by X-ray telescopes with improved spectral resolution. We have also estimated the expected spectral and timing signatures resulting from the MHD instabilities. We find that CRSF spectra are expected to broaden, and a broad band noise component is expected to appear in the high frequency regime of the power density spectra, contributed by the dynamically fluctuating structures formed due to the instabilities.

We finally summarise the main results and conclusions of the work in Chapter 6. We discuss the implications of the results on the evolution of the magnetic field of neutron stars under the influence of accretion. We finally discuss avenues along which the current work can be extended.

Weak Lensing Probes of Cosmology

Aditya Rotti

A multitude of current cosmological observations are successfully explained by the big bang cosmology. The spatially flat ΛCDM model of cosmology requires only 6 free parameters to fit these observations. Specifically, the direction independent two point statistic, better known as the angular power spectrum of the CMB temperature anisotropy measurements that have been measured with extreme precision by PLANCK are fit exceedingly well by this simple model.

The Bipolar Spherical Harmonic (BipoSH) coefficients $A^{LM}_{l_1 l_2}$ provide a very natural generalisation to the CMB angular power spectrum ($A^{00}_{ll} \sim C_l$). A measurement of non-vanishing BipoSH coefficients ($A^{LM}_{l_1 l_2}\ \forall\ L, M \neq 0$) is the basic criteria to search for violation from statistical isotropy.

Weak lensing due to the large scale structure (LSS) surrounding us results in the CMB temperature anisotropy map to get distorted. The LSS forms an effective lens, which induces a very specific form of statistical isotropy violation in the lensed CMB maps. Motivated by this fact, we study the lensed CMB sky in the BipoSH representation. We show that, studying the lensed CMB map reveals a wealth of information. It provides a tool to study the weak lensing without making assumptions about isotropy of the universe, and the results reduce to the standard lensing results in the appropriate limits.

While weak lensing generates some power in the BipoSH coefficients, it also couples power across different multipoles in the CMB angular power spectrum. Apart from the scalar perturbations associated with the LSS responsible for this lensing, the metric perturbations are also composed of tensor metric perturbations associated with gravitational waves (GW). These GW are predicted to exist, however, their detection has been elusive. Like LSS induced lensing, GW can also result in the lensing of the CMB photons. By studying the GW lensing induced modification to the CMB angular power spectra, we show that it is possible to derive stringent constraints on the energy density of these GW from current measurements of the CMB temperature and polarization power spectra. In the process, we have also corrected the GW lensing kernels given in existing literature.

One of the fundamental assumptions made while building the ΛCDM model of cosmology is that of isotropy. With almost full sky measurements of CMB temperature anisotropies made available through measurements made by the WMAP and PLANCK satellites, it is now possible to test the validity of this assumption. One of the primary motives of this thesis has been to device tests to search for deviations from the standard model of cosmology.

We present the details of the BipoSH re-analysis of the WMAP seven year maps,which is primarily to address the quadrupolar anomaly, and discuss how a local large deviation from homogeneity in the distribution of LSS could possibly result in such non-vanishing BipoSH coefficients, through weak lensing. We end this discussion with an explanation for these BipoSH detections as arising from viewing the CMB sky through a non-circular beam.

Though searching for non-vanishing BipoSH coefficients forms a model independent test of violation of statistical isotropy, it is only sensitive to relatively large deviations from isotropy. We argue that, assuming the form or model of isotropy violation, it is possible to devise more sensitive tests by constructing optimal estimators from linear combinations of BipoSH coefficients. We use such an optimal estimator to search for a modulation signal in the PLANCK maps. The results of this analysis have been reported as a part of the recently announced first cosmology results by Planck on *Isotropy and Statistics of the CMB*.

Aspects of Quantum Field Theory in Black Holes and Cosmological Spacetimes

Suprit Singh

Quantum field theory in curved spacetimes has offered some remarkable insights in the last few decades by uncovering new physical phenomenon, for example, the Fulling-Davies-Unruh effect in accelerated frames, the Hawking evaporation of black holes, particle creation in expanding universe, inflationary physics of the early universe, and the thermodynamic aspects of horizons in general. Also, it is a well established framework to work in, since we are, as yet, unclear about the physics at Planck scales. The features emerging out of the study of quantum fields in curved spacetime can provide hints on what we can expect from a complete theory of quantum gravity.

However, we still have many conceptual issues which need to be sorted out, even at the level of studying quantum fields in curved spacetimes. A careful analysis of some of these important issues with fresh approaches forms the main theme of this thesis. The thesis is divided into two parts — the first part takes up the aspects related to black holes and the second part deals with the cosmological spacetimes — both of which we briefly describe below.

Solving the complete quantum dynamics of system, which can be divided into two sub-systems interacting in a very non-trivial fashion is generally not possible. The system of *classical* gravity and *quantized* matter fields falls in this category. In classical general relativity, gravity is described geometrically through the curvature of spacetime, dynamics of which is governed by the Einstein equations sourced by the classical matter stress-energy tensor. Since matter is inherently quantum mechanical, this procedure requires a modification. Being complicated to solve in the complete quantum domain, we invoke the semi-classical approximation, which leads to quantum field theory in curved spacetimes. This assumes gravity as a classical background sourced by a classical stress-energy tensor with quantum fields propagating on it, which can backreact on the geometry through (re-normalized) expectation value of the stress-energy tensor. This is handled through the concept of effective action, which is obtained by integrating out the quantum degrees of freedom in the complete path integral for the system. The effective action then encodes the effect of fluctuations in the quantum sub-system and its variation like a classical action gives the effective dynamical equations for the classical background.

There are two effects that arise from the interaction of quantum fields in external backgrounds, viz., vacuum polarization and particle production. These are given by the real and imaginary parts of the effective action respectively. The vacuum polarization can be handled perturbatively, but the particle production can be either a perturbative or non-perturbative effect. For example, in the case of Schwinger effect — the production of charged particle pairs out of vacuum in the presence of strong external electric fields — the particle production is non-analytic in the coupling constant and cannot be obtained by any perturbative means. We, thus, need to compute the imaginary part of the effective action in a non-perturbative calculation to ascertain the particle creation in the system. However, we can only handle quadratic actions exactly making it impossible to compute the effective action exactly in a generic situation. It would be useful to have an alternative quantity related to the effective action, which can be characterized by some independent procedure so as to bypass the calculation of the effective action itself. We show that there is such a quantity, the complex path, which is the solution of the effective dynamical equation obtained by varying the effective action. The complex path can alternatively be defined and computed as the path integral average in point-particle quantum mechanics. We apply this formalism to two examples including a non-trivial example of an inverse square potential, which is related to the dynamics of the scalar field in Schwarzschild spacetime. We then show that the modulus square of the complex path in this case contains all the features of the black hole radiance.

Further, in the case of black hole physics, the Hawking effect is usually understood as the thermal flux of particles with temperature, $T_H = (1/8\pi)M$ observed by the asymptotic observer far away from the black hole horizon. However, we can also have non-asymptotic observers in the black hole spacetime and of particular interest are the radially infalling observers. These observers have non-stationary trajectories as they traverse through the black hole spacetime passing through the horizon, towards the singularity. It is not very clear what they would perceive as regards to the Hawking effect. We study the response of Unruh-DeWitt (UDW) detectors on various non-asymptotic trajectories and show that there is a significant departure from the standard picture. This is also confirmed by an alternate set of observables, the energy density and flux built out of the (re-normalized) stress-energy tensor of the quantum field.

The second part of the thesis takes up the analysis of quantum fields in the cosmological spacetimes. The de Sitter spacetime plays an important role in cosmology, since the inflationary phase of the universe is very close to the de Sitter geometry and so is the current Λ-dominated accelerated phase. The de Sitter spacetime, like the Schwarzschild spacetime, has a horizon structure when expressed in the static coordinates with a thermodynamic interpretation and temperature, $T = H/2\pi$. However, in the cosmological context, the background is not perfectly de Sitter and the usual techniques of associating the temperature with the spacetime do not apply directly in this case. We have to work in Friedmann coordinates and there are associated ambiguities with defining the vacuum states in such a time-dependent background.

The question arises as to whether we can say something about the particle content and the thermality of states working entirely in the Friedmann coordinates. We show that this is indeed possible. We define two natural vacuum states: (i) the Bunch-Davies vacuum, and (ii) the co-moving vacuum using appropriate boundary conditions and then, using mixing coefficients and the detector response, compare and contrast the differences brought about by the different choices in both (1+1) and (1+3) dimensions. We find that contrary to expectations, the (1+1) and (1+3) dimensions behave very differently. While, we have the Planckian structure for both the vacuum states, which are identical in (1+1), the mixing coefficients in (1+3) dimensions are not Planckian (and have an extra multiplicative frequency dependent factor) for the Bunch-Davies state and for the comoving vacuum state, there is also an extra factor of $\sqrt{N(N+1)}$. This factor comes from the interference effect and can be identified with photon fluctuations in a thermal bath. We also study these aspects in quasi–de Sitter spacetimes, which deviate only slightly from the de Sitter spacetime for the perturbative framework remains valid. We take up a particular example of the deviations in de Sitter spacetime due to the presence of pressure-free matter which to the linear order give corrections to thermal spectrum in the form of spectral indices.

Having studied the aspects of thermality in (quasi-)de Sitter spacetimes, we finally take up the evolution of quantum field in a (toy) universe with three stages, viz., (i) an inflationary de Sitter phase, (ii) a radiation dominated phase, and (iii) the late-time Λ-dominated accelerated phase. (This toy universe is quite close to our real universe, since the matter dominated phase between the radiation and Λ phases lasted for only 4 decades compared to 24 decades of the radiation-dominated era.) We look at the instantaneous particle content and also quantify the quantum-to-classical transition in terms of the classicality parameter through the whole history of the universe. This has important implications in cosmology, since a quantum-to-classical transition is supposed to have occurred so that the quantum fluctuations during the inflationary phase of the universe act as seeds for anisotropies and present-day large scale structures in our universe.

FACILITIES AT IUCAA

COMPUTER CENTRE

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

In the past year, the Campus Area Network (CAN) was upgraded from 1G to 10 G up-links based on Layer 3 Core switches and Layer 3 capable Edge switches from Brocade. Prior to the network upgrade, OM4 multimode fibre was laid across the campus to support the enhanced bandwidth. The CAN has now become much more resilient with redundant core 10 G fibre switches and dual 10 G up-links to various edge locations.

In September 2014, VMWARE virtual desk top environment was upgraded with better back-end servers and storage resources to offer VMWARE horizon desk top environment for the users from administration. The thin clients at the users' end too have been replaced with VMWARE aware (PCOIP) thin clients for better performance.

During January 2015, provisioned desktops for the visitors and associates, were replaced with thin clients serving dual Operating Systems (OS) namely Windows and Linux. This has made the management of desktops and up-gradation of OS and relevant application software easy as everything is being made available centrally.

In March 2015, five year old wireless local area network (WLAN), based on Ruckus technologies was upgraded in stages by replacing (i) two centralized controllers with enterprise class ones to support many new features, and (ii) a few Access Points with new generation that support more number of connections and ever increasing number of mobile devices.

The Computer Centre continues to extend technical support to visitors, project students, IUCAA associates as well as visitors from the universities and institutions within India and abroad.

LIBRARY

During this year, the library has added 109 books, 340 e-books and 400 bound volumes, bringing the total collection to 25,922. 10 DVDs were added to the collection of the Muktangan Vidnyan Shodhika (MVS) library. The library subscribes to 126 journals, both, print and online. In addition, the library receives access to approximately 3,678 online journals courtesy INFLIBNET through the UGC-INFONET programme, which consists of e-journals from 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 library continued the year long library trainee programme, in which two library trainees were selected. This programme aims to impart in-depth knowledge of traditional and electronic resources along with exposure to a range of library activities, from processing library materials, addressing circulation desk queries, shelving, and journal to providing reference service to users.

2. The IUCAA library acquired Springer e-book collection in Physics and Astronomy for the copyright year 2014.

3. The library received and fulfilled 196 full-text article requests from 78 academics (including students) through e-mail/post/personal visits and interlibrary loan requests.

4. 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 made available through the IUCAA Institutional Repository using DSpace (**http://www.iucaa.in:8080/jspui/**).

5. Online access to the IUCAA Bulletin and Annual Report is provided using Open Journals (**http://ojs.iucaa.in/**).

6. Access to recorded lectures delivered by T. Padmanabhan is available through the Network Assisted Server (NAS), on a username and password basis (**http://www.iucaa.in/~archives/TP/index.html**).

VIRTUAL OBSERVATORY

AstroStat

The R programming language is the standard choice among scientists across several disciplines for statistical analysis of structured data. However, it has an unusual syntax and a relatively steep learning curve.

AstroStat is a web based application, developed by Virtual Observatory - India, which allows scientists to perform common statistical analysis by interacting with an easy-to-use graphical interface. The user chooses the data, the tests to be performed from an extensive list and provides necessary inputs to AstroStat, which translates them into an R programme. This programme is executed by R behind the scenes and the output returned is presented in a neatly formatted fashion to the end user. AstroStat includes 31 commonly used statistical tests grouped in 3 categories, and has been programmed in a manner that additional tests can be added with ease by the developers. Novel features also include support for the web SAMP (Simple Application Messaging Protocol) and TAP (Table Access Protocol), which allow users to use data repositories such as Vizier to directly transfer data to AstroStat for analysis. An article describing the tool, written by **Ajit Kembhavi, Ajay Vibhute, Santosh Jagade, Kaustubh Vaghmare** et al. has been published in the Astronomy and Computing journal's special Virtual Observatory issue.

VOI-PyMorph

PyMorph is a stand-alone Python pipeline described in "PyMorph: Software for Automated Galaxy Morphological Parameter Estimation", initially by Vinu et al. (2010). The pipeline is designed for the estimation of structural parameters of galaxies and supports parametric fits through two-dimensional bulge-disc decomposition and also non-parametric indicators of morphology such as concentration, asymmetry, etc. It also provides a *find-and-fit* mode, where all galaxies in an image can be fitted using a single command. PyMorph uses GALFIT (Peng et al. 2002) for bulge-disk decomposition of galaxies, SExtractor (Bertin et al. 1996) for determining the guess values for model fitting, and IRAF / PyRAF for fitting ellipses to the isophotes of a galaxy. PyMorph uses its own modules to calculate concentration index, asymmetry, clumpness, Gini coefficient and the second order moment of the brightest 20% pixels of galaxies (M20), referred to as the CASGM parameters in literature.

VOI-PyMorph is an easy-to-use web based graphical interface, developed by Virtual Observatory - India to this pipeline. This allows astronomers to derive morphological parameters for galaxy images through a simple GUI, which interacts with PyMorph installed on the VOI server. The web interface is mainly divided into two sections - Input Form and Job Output. The Input Form allows user to provide the image and weight files from his/her local machine, which gets uploaded to VOI server for further processing. In addition to this, user has the option to modify various PyMorph configuration parameters such as pixel scale, magnitude zero point, PSF image size, etc. and submit the job request. After submitting, VOI-PyMorph generates a JobID (RequstID) and invokes the PyMorph pipe-line asynchronously, based on users input configuration. The Job Output section provides the job status (RUNNING/ COMPLETED/FAILED), date and time when job has been submitted and a job label provided by user. To view successfully completed job output, user can simply click on RequestID, which pops-up the window and displays derived morphological parameters for provided galaxy image file along with various graphs.

PUBLIC OUTREACH HIGHLIGHTS

VACATION STUDENTS' PROGRAMME

The Vacation Students' Programme (VSP) was conducted during May - July 2014, and was coordinated by R. Srianand.

[For details see Khagol, Issue No. 99, July 2014]

NATIONAL SCIENCE DAY

The National Science Day was celebrated at IUCAA on February 28, 2015.

[For details see Khagol, issue No. 102, April 2015]

SCHOOL STUDENTS' SUMMER PROGRAMME

School Students' Summer Programme was conducted at IUCAA during April 22 - May 23, 2014.

[For details see Khagol, Issue No. 99, July 2014]

SUMMER ASTRONOMY CAMP

The new format Astronomy Camp was conducted at IUCAA during April 29 - May 23, 2014.
[For details see Khagol, Issue No. 99, July 2014]

THE UNIVERSE - A TOUCHING EXPERIENCE

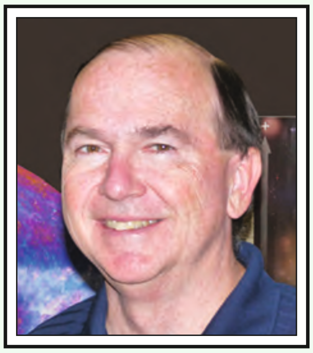
WORKSHOP ON BASIC ASTRONOMY AND TELESCOPE MAKING

Workshop on Basic Astronomy and Telescope Making for School Students was organised jointly by the Kohima Science College and IUCAA, at Kohima, during September 26 - 27, 2014.
[For details see Khagol, issue No. 100, October 2014]

PUBLIC LECTURES

On July 31, 2014, **Gordon Squires,** Communications and Education lead, Thirty Metre Telescope (TMT) gave a public lecture on A Universe of Wonder. He shared exciting recent discoveries enabled by ground- and space-based telescopes, with some personal stories of how he helped share them with the world. He also described the progress towards astronomy's next-generation observatory, TMT.

On August 21, 2014, **T. Padmanabhan,** IUCAA, interacted with the public on the topic Cosmic History and Mysteries. He described our current understanding of the universe, emphasizing some recent work, which has the potential to solve the enigma of dark energy. Some deep mysteries about the cosmos were also highlighted, especially regarding its composition.



On September 19, 2014, **Theodore Williams,** Director, South African Astronomical Observatory, Cape Town and Professor of Physics and Astronomy, Rutgers University, shared his ways of "Doing Astronomy, the Hard(ware) Way - Reflections on Travels with Instrumentation". This public lecture was a discussion on experiences of Williams, both successful or not, and the attempt to blend Science and Instrumentation, an effort that strongly influences the course of astronomical investigation and discovery.

POPULAR LECTURES

Varun Bhalerao

1. *Khagolshastratil bharatachi bharari* (Devolopment in astronomy) (in Marathi), Hujurpaga Girls School, Pune, July 16, 2014.
2. *Astronomy projects for beginners*, Hands-on course in astronomy, Fergusson College, Pune, December 18, 2014.
3. *Engineering, science and demonstrations*, Vishwakarma Institute of Information Technology, Pune, December 18, 2014.
4. *Beyond the human eye*, Frontiers in Physics - VIII, Fergusson College, Pune, January 29, 2015.

Naresh Dadhich

Einstein's relativity for everyone, Czech Academy of Science, Prague, Czech Republic, June 26, 2014.

Ajit Kembhavi

1. *Next generation telescopes for astronomy*, 27^{th} Jyotirvidya Parisanstha, Tilak Smarak Mandir, Pune, April 27, 2014.
2. Giant telescopes for astronomy, DST INSPIRE Camp, IISER, Pune, May 16, 2014.
3. *The Universe*, National Institute of Virology, Pune, May 1, 2014.
4. *Precision measurements in astronomy : Are they really possible and useful?*, National Physical Laboratory, New Delhi, May 20, 2014.
5. *Was Einstein right about gravitational waves?*, LIGO-India Experiment, S.G.T.B. Khalsa College, New Delhi, August 7, 2014.
6. *New technology for the edge of the universe – Great optical telescopes for the near future?*, School on Recent Trends in Astrophysics and Cosmology, Manipal Centre for National Sciences, Manipal University, September 4, 2014.
7. *Big data in astronomy*, Late Dr. V Sundararajan Memorial Lecture Series, C-DAC, Pune, October 10, 2014.
8. *Gravity*, Second Saturday Lecture, IUCAA, Pune, November 15, 2014.
9. *Gurutwakarshan* (Marathi), Second Saturday Lecture, IUCAA, Pune, November 15, 2014.
10. *Singularities in Einstein's theory of gravity and the mass of black holes*, Frontiers in Physics - Astro Club, Fergusson College, Pune, January 29, 2015.

Jayant Narlikar

1. *Searches for life outside the Earth*, Second Saturday Lecture , IUCAA, Pune, July 12, 2014.
2. *Pruthvipalikade jeevshrusticha shodh* (Searches for life outside the Earth) (in Marathi), Second Saturday Lecture, IUCAA, Pune, July 12, 2014.
3. *Vidnyanachi godi kashi vadhavavi?* (How to develop an interest in science?) (in Marathi), Samarth Vidyalaya, Pune, August 2, 2014.
4. *Vaidnyanik drushtikon* (Scientific outlook) (in Marathi), Samarth Vidyalaya, August 2, 2014.
5. *Are we alone in the universe?*, Recorded by Igniting Minds, Bengaluru at IUCAA and telecasted all over India in various colleges and universities, August 8, 2014.
6. *Vishwa kharokhar kase ahe,* (What is the universe really like?) (in Marathi), AASTRONOMICA Club, N.M.V. Girls High School, Pune, August 10, 2014.
7. *Vaidnyanik drushtikon ani apla samaj* (Scientific outlook and our society) (in Marathi), Dr. Narendra Dabholkar Vivek Vyakhyanmala, Nashik, August 20, 2014.

8. *The amazing world of astronomy*, Astronomy and Astrophysics Club "Aakashganga', Indian Institute of Science Education and Research, Pune, October 10, 2014.

9. *The amazing world of astronomy*, Science INSPIRE Internship Programme, National Institute of Oceanography, Goa, October 31, 2014.

10. *Pustakanchya jagat* (In the world of books) (in Marathi), Akshardhara (for school students), Tilak Smarak Mandir, Pune, November 14, 2014.

11. *Vishwat aapan ekte aahot ka?* (Are we alone in the universe?) (in Marathi), Hemant-Mani Vyakhyanmala, Swami Vivekanand Pratisthan, Pune, November 15, 2014.

12. *The amazing world of astronomy*, 7th Science Conclave, Indian Institute of Information Technology, Allahabad, December 9, 2014.

13. *The amazing world of astronomy,* INSPIRE Camp, Shri. Shivaji Education Society Amravati's Shivaji Science College, Nagpur, January 13, 2015.

14. *Maze vidnyankatha vishwa* (My world of science fiction) (in Marathi), Akhil Bharatiya Sahitya Mahamandal, Progressive Education Society's Hall, Pune, January 20, 2015.

15. *51st Annual Convocation Address*, Shivaji University, Kolhapur, January 29, 2015.

16. *Kal, avakash aur gurutvakarshan* (Time, space and gravitation) (in Hindi), Ghasi Das Museum, Raipur, February 6, 2015.

17. *Vidnyankatha* (Science fiction) (in Marathi), Bharatiya Stree Shakti Jagaran Sanghatana, Bharat Itihas Sansodhan Mandal, Pune, February 14, 2015.

18. *A search for micro-life in the Earth's atmosphere*, Tech Mahindra Ltd., Pune, February 20, 2015.

19. *Are we alone in the universe?*, JIGYASA'15, Indian Institute of Technology, Banaras Hindu University, Varanasi, March 21, 2015.

Aseem Paranjape

A journey through the cosmic web, National Science Day, IUCAA, February 28, 2015

Krishnamohan Parattu

*Scalars, vectors, tensors: Facts of the Universe, S*econd Saturday lecture, IUCAA, December 13, 2014.

POPULAR ARTICLES

Jayant Narlikar

The egoist's guide to the galaxy, The Asian Age, April 9, 2014.

What ails Indian Science?, The Asian Age, May 7, 2014.

Ladder to virtual libraries, The Asian Age, June 4, 2014.

Curious case of dark matter, The Asian Age, July 2, 2014.

Physics, are we done?, The Asian Age, July 23, 2014.

Speakers anonymous, The Asian Age, August 27, 2014.

Strange tales of the stars, The Asian Age, September 24, 2014.

The eccentric geniuses, The Asian Age, October 22, 2014.

Quo vadis cosmology?, Khagol, October 2014.

Imagination is limited, not physics, The Asian Age, November 19, 2014.

Of god and cheeky geeks, The Asian Age, December 17, 2014.

Logical thinking in Mathematics and elsewhere, Manorama Year Book 2015, 140.

Tracing supernova 1054, The Asian Age, January 14, 2015.

The spirit of inquiry, The Asian Age, February 19, 2015.

Where's science in the bombast?, The Asian Age, March 11, 2015.

Dharti ka ghoda (in Hindi) (The Trojan horse), Navneet Hindi Digest, February 2015, 64.

Uranus ani Neptune: Kon mhanta vaidnyanik chukat nahit? (in Marathi) (Uranus and Neptune : Who says that scientists are infallible?), Saptarang, Sakal, April 6, 2014.

Eka prakhyat prayogamagach ramayan! (in Marathi) (The trials and tribulations behind a famous experiment), Saptarang, Sakal, May 4, 2014.

Einsteinla 'Nobel' kasa milala? (in Marathi) (How Einstein was awarded the Nobel Prize?), Saptarang, Sakal, June 1, 2014.

Tarkashudha vicharsarni ani ganit (in Marathi) (Mathematics and logical thinking), Saptarang, Sakal, July 6, 2014.

Bharatiya vidnyanabaddalcha yakshaprashna (in Marathi) (A question about Indian science), Saptarang, Sakal, August 3, 2014.

Sansmarniya mohim (in Marathi) (A memorable campaign), Lokmat, August 17, 2014.

Narendra Dabholkar yanchyabarobarchi ek sansmarniya mohim (in Marathi) (An operation with Narendra Dabholkar), Saptahik Sadhana, August 30, 2014.

Samarabhshuraha khalu bharatiyaha (in Marathi) (We Indians make great beginnings only), Saptarang, Sakal, September 7, 2014.

Patrick Moore yanchya 'asmani' aakhyaeka (in Marathi) (Heavenly tales of Patrick Moore), Saptarang, Sakal, October 5, 2014.

Ek sansmarniya mohim (in Marathi) (A memorable campaign), Saptahik Sadhana, October 11, 2014.

Wrangleriche avhan (in Marathi) (The challenge of Wranglership), Manashakti Diwali Issue, 2014, 22.

Aatpatnagaratalya metrochi kahani (in Marathi) (The story of metro in a typical city), Saptarang, Sakal, November 2, 2014.

Vedhshalenchya ramya parisarat (in Marathi) (In the pleasant environment of observatories), Tonic, 2014, 190.

Avakash ek prayogshalach (in Marathi) (Space is a big laboratory), Mitrangan (Diwali Issue), 2014, 14.

IUCAAchi gosta (in Marathi) (The IUCAA story), Maze Punyabhushan (Diwali Issue), 2014, 60.

Gosti ganitnyanchya (in Marathi) (Tales of mathematicians), Saptarang, Sakal, December 7, 2014.

Vaidnyanikanche vinod (in Marathi) (Amusing episodes of scientists), Saptarang, Sakal, January 4, 2015.

Pariksha paddhati: Kahi vichar (in Marathi) (A few thoughts on our examination system), Shikshan Sankraman, January 2015, 5.

Khagolvidnyanache don mahaprakalpa (in Marathi) (Two big projects in astronomy and astrophysics), Saptarang, Sakal, February 1, 2015.

Puranatil vangi 'vidnyanvikasa' chi (in Marathi) (Speculations about science in the Puranas), Saptarang, Sakal, March 1, 2015.

Radio/TV Programmes

Jayant Narlikar

From atoms to the universe, All India Radio, Delhi, October 12, 2014.

Eureka, Rajya Sabha TV, November 22 and 23, 2014.

Research by Visiting Associates

Sk. Saiyad Ali

Visibility-based angular power spectrum estimation in low-frequency radio interferometric observations

We present two estimators to quantify the angular power spectrum of the sky signal directly from the visibilities measured in radio interferometric observations. This is relevant for both the foregrounds and the cosmological 21-cm signal buried therein. It is restricted to the Galactic synchrotron radiation, the most dominant foreground component after point source removal. Our theoretical analysis is validated using simulations at 150 MHz, mainly for GMRT and also briefly for LOFAR. The Bare Estimator uses pairwise correlations of the measured visibilities, while the Tapered Gridded Estimator uses the visibilities after gridding in the uv plane. The former is very precise, but computationally expensive for large data. The latter has a lower precision, but takes less computation time, which is proportional to the data volume. The latter also allows tapering of the sky response leading to sidelobe suppression, an useful ingredient for foreground removal. Both estimators avoid the positive bias that arises due to the system noise. We consider amplitude and phase errors of the gain, and the w-term as possible sources of errors. We find that the estimated angular power spectrum is exponentially sensitive to the variance of the phase errors but insensitive to amplitude errors. The statistical uncertainties of the estimators are affected by both amplitude and phase errors. The w-term does not have a significant effect at the angular scales of our interest. We propose the Tapered Gridded Estimator as an effective tool to observationally quantify both foregrounds and the cosmological 21 cm signal. This work has been done in collaboration with S. Choudhuri, S. Bharadwaj, and A. Ghosh.

Prospects for detecting the 326.5 MHz redshifted 21 cm HI signal with the Ooty Radio Telescope (ORT)

Observations of the redshifted 21 cm HI fluctuations promise to be an important probe of the post-reionization era ($z \leq 6$). In this work, we calculate the expected signal and foregrounds for the upgraded Ooty Radio Telescope (ORT), which operates at frequency $\nu_o = 326.5$ MHz, which corresponds to redshift $z = 3.35$. Assuming that the visibilities contain only the HI signal and system noise, we show that a 3σ detection of the HI signal (~ 0.54 mJy) is possible at angular scales $11'$ to $3°$ with $\approx 1,000$ hours of observation. Foreground removal is one of the major challenges for a statistical detection of the redshifted 21 cm HI signal. We assess the contribution of different foregrounds and find that the 326.5 MHz sky is dominated by the extragalactic point sources at the angular scales of our interest. The expected total foregrounds are $10^4 - 10^5$ times higher than the HI signal. This work has been done in collaboration with S. Bharadwaj.

G. Ambika

Dynamical behaviours in time-delay systems with delayed feedback and digitized coupling

We consider a network of delay dynamical systems connected in a ring via uni-directional positive feedback with constant delay in coupling. For the specific case of Mackey-Glass systems on the ring topology, we capture the phenomena of amplitude death, isochronous synchronization and phase-flip bifurcation as the relevant parameters are tuned. Using linear stability analysis and Master Stability Function approach, we predict the region of amplitude death and synchronized states respectively in the parameter space and study the nature of transitions between the different states. For a large number of systems in the same dynamical configuration, we observe splay states, mixed splay states and phase locked clusters. We extend the study to the case of digitized coupling and observe that these emergent states still persist. However, the sampling and quantization reduce the regions of amplitude death and induce phase-flip bifurcation. This work has been done in collaboration with Chiranjit Mitra, and Soumitro Banerjee.

Novel coupling scheme to control dynamics of coupled discrete systems

We present a new coupling scheme to control spatio-temporal patterns and chimeras on 1-d and 2-d lattices and random networks of discrete dynamical systems. The scheme involves coupling with an external lattice or network of damped systems. When the system network and external network are set in a feedback loop, the system network can be controlled to a homogeneous steady state or synchronized periodic state with suppression of the chaotic dynamics of the individual units. The control scheme has the advantage that its design does not require any prior information about the system dynamics or its parameters and works effectively for a range of parameters of the control network. We analyze the stability of the controlled steady state or amplitude death state of lattices using the theory of circulant matrices and Routh-Hurwitz criterion for discrete systems and this helps to isolate regions of effective control in the relevant parameter planes. The conditions, thus, obtained are found to agree well with those obtained from direct numerical simulations in the specific context of lattices with logistic map and Henon map as onsite system dynamics. We show how chimera states developed in an experimentally realizable 2-d lattice can be controlled using this scheme. We propose this mechanism can provide a phenomenological model for the control of spatio-temporal patterns in coupled neurons due to non-synaptic coupling with the extra cellular medium. We extend the control scheme to regulate dynamics on random networks and adapt the master stability function method to analyze the stability of the controlled state for various topologies and coupling strengths. This work has been done in collaboration with Snehal Shekatkar.

Prasad Basu and Soumen Mondal

The relativistic equation of state in accretion and wind flows

In this study, we derive a 4-velocity distribution function for the relativistic ideal gas following the original approach of Maxwell-Boltzmann (MB). Using this distribution function, the relativistic equation of state (EOS): $\rho - \rho_0 = (\gamma - 1)^{-1} p$, is expressed in the parametric form: $\rho = \rho_0 f(\lambda)$, and $p = \rho_0 g(\lambda)$, where λ is a parameter related to the kinetic energy, and hence, to the temperature of the gas. In the non-relativistic limit, this distribution function perfectly reduces to original MB distribution and the EOS reduces to $\rho - \rho_0 = \frac{3}{2} p$, whereas in the extreme ultra-relativistic limit, the EOS becomes $\rho = 3p$ correctly. Using these parametric equations, the adiabatic index γ $(= \frac{c_p}{c_v})$ and the sound speed a_s are calculated as a function of λ. They also satisfy the inequalities: $\frac{4}{3} \leq \gamma \leq \frac{5}{3}$ and $a_s \leq \frac{1}{\sqrt{3}}$ perfectly. The computed distribution function, adiabatic index γ, and the sound speed a_s are compared with the results obtained from the canonical ensemble theory which nicely match with the standard results (Synge, 1957 and Chandrasekhar, 1939).

The main advantage in using the EOS is that the probability distribution function can be factorized and therefore, may be helpful to solve complex dynamics of the astrophysical system. Interestingly, in one of the astrophysical applications it revels that shocks in accretion flows become unlikely and except for the region very nearby to the compact object, the EOS remains non-relativistic (Mondal, Basu, 2011). We, therefore, conclude that the new form of EOS will be helpful to verify many conventional ideas in many astrophysical problems.

Koushik Chakraborty and Farook Rahaman

A new relativistic model of hybrid star with interactive quark matter and dense baryonic matter

We propose a relativistic model of hybrid star admitting conformal symmetry considering quark matter and baryonic matter as two different fluids. We define interaction equations between the normal baryonic matter and the quark matter, and study the physical situations for repulsive, attractive and zero interaction between the constituent matters. From the interaction equations, we find out the value of the equation of state (EOS) parameter for normal baryonic matter, which is found to be consistent with the value obtained from the Walecka model for nucleonic matter at high density. The measured value of the Bag constant is used to explore the spacetime geometry inside the star. The theoretical mass-radius values are compared with the available observational data of the compact objects. From the nature of the match with the observational data, we predict the nature of interaction that must be present inside the hybrid stars. This work has been done in collaboration with Arkopriya Mallick.

Koushik Chakraborty, Farook Rahaman and Saibal Ray

Possible features of galactic halo with electric field and observational constraints

Observed rotational curves of neutral hydrogen clouds strongly support the fact that galactic halo contains huge amount of non-luminous matter, the so called gravitational dark matter. The nature of dark matter is a point of debate among the researchers. Recent observations reported the presence of ions of O, S, C, Si, etc. in the galactic halo and intergalactic medium. This supports the possibility of existence of electric field in the galactic halo region. We, therefore, propose a model of galactic halo considering this electric field arising due to charged particles as one of the inputs for the background spacetime metric. Considering dark matter as an anisotropic fluid, we obtain the expressions for energy density and pressure of dark matter and consequently the equation of state of dark matter. Various other aspects of the solutions are also analyzed along with a critical comparison and constraints of different observational evidences. This work has been done in collaboration with Arka Nandi, and Nasarul Islam.

Subenoy Chakraborty

Is emergent universe a consequence of particle creation process?

A model of an emergent universe is formulated using the mechanism of particle creation. Here, the universe is considered as a non-equilibrium thermodynamical system with dissipation due to particle creation mechanism. The universe is chosen as spatially flat FRW spacetime and the cosmic substratum is chosen as perfect fluid with barotropic equation of state. Both first and second order deviations from equilibrium prescription are considered and it is found that the scenario of emergent universe is possible in both the cases.

Complete cosmic scenario from inflation to late time acceleration: Non-equilibrium thermodynamics in the context of particle creation

This work deals with the mechanism of particle creation in the framework of irreversible thermodynamics. The second order non-equilibrium thermodynamical prescription of Israel and Stewart has been presented with particle creation rate, treated as the dissipative effect. In the background of a flat Friedmann-Robertson-Walker (FRW) model, we assume the non-equilibrium thermodynamical process to be isotropic so that the entropy per particle does not change, and consequently the dissipative pressure can be expressed linearly in terms of the particle creation rate. Here, the dissipative pressure behaves as a dynamical variable having a non-linear inhomogeneous evolution equation and the entropy flow vector satisfies the second law of thermodynamics. Further, using the Friedmann equations and by proper choice of the particle creation rate as a function of the Hubble parameter, it is possible to show (separately) a transition from the inflationary phase to the radiation era, and also from the matter dominated era to late time acceleration. Also, in analogy to analytic continuation, it is possible to show a continuous cosmic evolution from inflation to late time acceleration by adjusting the parameters. It is found that in the de Sitter phase, the co-moving entropy increases exponentially with time, keeping entropy per particle unchanged. Subsequently, the above cosmological scenarios have been described from a field theoretic point of view by introducing a scalar field having self-interacting potential. Finally, we make an attempt to show the cosmological phenomenon of particle creation as Hawking radiation, particularly during the inflationary era. This work has been done in collaboration with Subhajit Saha.

Ramesh Chandra

Can we explain atypical solar flares?

We use multi-wavelength high-resolution data from ARIES, THEMIS, and SDO instruments to analyze a non-standard, C3.3 class flare produced within the active region NOAA 11589 on October 16, 2012. Magnetic flux emergence and cancellation were continuously detected within the active region, the latter leading to the formation of two filaments. We analyze the magnetic topology of the active region using a linear force-free field extrapolation to derive its 3D magnetic configuration and the location of quasi-separatrix layers (QSLs), which are preferred sites for flaring activity. The topological analysis shows that the active region presented a complex magnetic configuration comprising several QSLs. The considered data set suggests that an emerging flux episode played a key role in triggering the flare. The emerging flux probably activated the complex system of QSLs, leading to multiple coronal magnetic reconnections within the QSLs. This scenario accounts for the observed signatures: The two extended flare ribbons are developed at locations matched by the photospheric footprints of the QSLs and are accompanied with flare loops that formed above the two filaments, which played no important role in the flare dynamics. This is a typical example of a complex flare that can a priori show standard flare signatures that are nevertheless impossible to interpret with any standard model of eruptive or confined flare. We find that a topological analysis, however, permitted us to unveil the development of such complex sets of flare signatures. This work has been done in collaboration with K. Dalmasse, B. Schmieder, and G. Aulanier.

Kelvin-Helmholtz instability in coronal mass ejecta in the lower corona

We model an imaged Kelvin-Helmholtz (KH) instability in coronal mass ejections (CME) in the lower corona by investigating conditions under which kink (m = 1 and m = −3) magneto-hydrodynamic (MHD) modes in a uniformly twisted flux tube moving along its axis become unstable. We employ the dispersion relations of MHD modes derived from the linearised MHD equations. We assum real wave numbers and complex angular wave frequencies, namely complex wave phase velocities. The dispersion relations are solved numerically at fixed input parameters (taken from observational data) and various mass flow velocities. It is shown that the stability of the modes depends upon four parameters: The density contrast between the flux tube and its environment, the ratio of the background magnetic fields in the two media, the twist of the magnetic field lines inside the tube, and the value of the Alfvén Mach number (the ratio of the tube velocity to Alfvén speed inside the flux tube). For a twisted magnetic flux tube at a density contrast of 0.88, a background magnetic field ratio of 1.58, and a normalised magnetic field twist of 0.2, the critical speed for the kink (m = −3) mode (where m is the azimuthal mode number) is 678 km s^{-1}, just as observed. The growth rate for this harmonic at KH wavelength of 18.5 Mm and ejecta width of 4.1 Mm is equal to 0.037 s^{-1}, in agreement with observations. The good agreement between observational and computational data shows that the imaged KH instability on CME can be explained in terms of an emerging KH instability of the m = −3 MHD mode in twisted magnetic flux tubes moving along its axis. This work has been done in collaboration with I. Zhelyazkov, and T. V. Zaqarashvili.

Suresh Chandra

Collisional rates for rotational transitions in H_2CO and their application

Formaldehyde (H_2CO) has always been of great importance for physicists. To analyze its spectrum, collisional rate coefficients are required. Their computation is quite tedious job. We calculate collisional rate coefficients for rotational transitions between 23 levels of each of the ortho and para species of H_2CO for kinetic temperatures 10, 20, 30, 40, and 50 K. The scattering problem is analyzed with the help of the computer code MOLSCAT, where the colliding partner is taken as the He atom. The required potential for interaction between H_2CO and He is calculated with the help of the software GAUSSIAN 2003, where the coupled-cluster CCSD(T) method and cc-pVTZ basis set are used. The Basis Set Superposition Errors (BSSE) are accounted for. The wave functions for the asymmetric top molecule H_2CO are expressed in terms of the Wigner D-functions and the expansion coefficients $g^K_{J\tau}$ are obtained. For the interaction potential obtained with the help of GAUSSIAN 2003, MOLSCAT is used to derive the parameters $q(L, M, M'|E)$ as a function of energy E of the colliding partner. After averaging the parameters $q(L, M, M'|E)$ over the Maxwellian distribution, the parameters $Q(L, M, M'|T)$ as a function of the kinetic temperature T in the cloud are obtained. The results are compared with the available data.

We also calculate radiative transition probabilities (Einstein A-coefficients) for transitions between 23 rotational levels for each of the ortho and para species of H_2CO. Finally, for ortho-H_2CO, we solve a set of 23 statistical equilibrium equations coupled with 39 equations of radiative transfer and discussed anomalous absorption of the $1_{11} - 1_{10}$ transition of H_2CO at 4.830 GHz. This work has been done in collaboration with Monika Sharma, M. K. Sharma, and U. P. Verma.

Suggestion for search of H_2CSi molecule in the interstellar medium

For understanding silicon chemistry in the interstellar medium, identification of large number of Si-bearing molecules in the medium is required. Ten Si-bearing molecules (SiO, SiS, SiC, SiN, *c*-SiC_2, SiCN, SiNC, *c*-SiC_3, SiC_4 and SiH_4) have been identified in the interstellar medium. Izuha, *et al.*, recorded microwave spectrum of H_2CSi and made an unsuccessful attempt for its identification in IRC +10216, Ori KL, Sgr B2 through its $7_{17} - 6_{16}$ transition at 222.055 GHz. Using rotational and distortional constants for H_2CSi, we calculate radiative transition probabilities and line strengths for transitions between rotational levels lying below 100 cm^{-1}. We find that 7 lines of ortho-H_2CSi and 3 lines of para-H_2CSi have the value of Einstein A-coefficient larger than 10^{-5} s^{-1}. These lines may help in identification of H_2CSi in the interstellar medium. The Einstein A-coefficient for $7_{17} - 6_{16}$ transition of H_2CSi is 5.24×10^{-6} s^{-1}. This work has been done in collaboration with Monika Sharma, M. K. Sharma, and U. P. Verma.

Suchetana Chatterjee

X-ray emissions in non-AGN galaxies at $z \sim 1$

Using data from the DEEP2 galaxy redshift survey and the All Wavelength Extended Groth Strip International Survey, we obtain stacked X-ray maps of galaxies at $0.7 < z < 1.0$ as a function of stellar mass. We compute the total X-ray counts of these galaxies and show that in the soft band (0.5 – 2 kev), there exists a significant correlation between galaxy X-ray counts and stellar mass at these redshifts. The best-fit relation between X-ray counts and stellar mass can be characterized by a power law with a slope of 0.58 ± 0.1. We do not find any correlation between stellar mass and X-ray luminosities in the hard (2 – 7 kev) and ultra-hard (4 – 7 kev) bands. The derived hardness ratios of our galaxies suggest that the X-ray emission is degenerate between two spectral models, namely point-like power-law emission and extended plasma emission in the interstellar medium. This is similar to what has been observed in low redshift galaxies. Using a simple spectral model, where half of the emission comes from power-law sources and the other half from the extended hot halo, we derive the X-ray luminosities of galaxies. The soft X-ray luminosities of our galaxies lie in the range $10^{39} - 8 \times 10^{40}$ ergs/s. Dividing our galaxy sample by the criteria $U - B > 1$, we find no evidence that our results for X-ray scaling relations depend on optical colour. This work has been done in collaboration with J. A. Newman, T. Jeltema, et al.

X-ray surface brightness profiles of active galactic nuclei in the extended Groth strip: Implications for AGN feedback

Using data from the All Wavelength Extended Groth Strip International Survey (AEGIS), we statistically detect the extended X-ray emission in the interstellar medium (ISM)/intra-cluster medium (ICM) in both active and normal galaxies at ($0.3 \leq z \leq 1.3$). For both active galactic nuclei (AGN) host galaxy and normal galaxy samples that are matched in rest frame colour, luminosity, and redshift distribution, we tentatively detect excess X-ray emission at scales of 1–10 arcsec at a few sigma significance in the surface brightness profiles. The exact significance of this detection is sensitive to the true characterization of Chandra's point spread function. The observed excess in the surface brightness profiles is suggestive of lower extended emission in AGN hosts compared to normal galaxies. This is qualitatively similar to theoretical predictions of the X-ray surface brightness profile from AGN feedback models, where feedback from AGN is likely to evacuate the gas from the centre of the galaxy/cluster. We propose that AGN that are intrinsically under-luminous in X-rays, but have equivalent bolometric luminosities to our sources, and will be the ideal sample to study more robustly the effect of AGN feedback on diffuse ISM/ICM gas. This work has been done in collaboration with J. A. Newman, T. Jeltema, et al.

Asis Chattopadhyay and Tanuka Chattopadhyay

Use of cross correlation function to study formation mechanism of massive elliptical galaxies

Spatial clustering nature of galaxies have been studied previously through auto correlation function. The same type of cross correlation function has been used in the present work to investigate parametric clustering nature of galaxies with respect to masses and sizes of galaxies. Here, formation and evolution of several components of nearby massive early type galaxies ($M_* \geq 1.3 \times 10^{11} M_\odot$) have been envisaged through cross correlations, in the mass-size parametric plane, with high redshift ($0.2 \leq z \leq 7$) early type galaxies (ETGs). It is found that the inner most components of nearby ETGs have significant correlation ($\sim 0.5 \pm (0.02 - 0.07)$) in the highest reshift range ($2 \leq z \leq 7$) called 'red nuggets', whereas intermediate components are highly correlated ($\sim 0.65 \pm (0.03 - 0.07)$) in the redshift range $0.5 \leq z \leq 0.75$. The outer most part has no correlation in any range, suggesting a scenario through in situ accretion. The above formation scenario is consistent with the previous results obtained for NGC5128 (Chattopadhyay, et al. (2009), and Chattopadhyay, et al. (2013)) and to some extent for nearby elliptical galaxies (Huang, et al. (2013)) after considering a sample of ETGs at high redshift with stellar masses greater than or equal to $10^{8.73} M_\odot$. So the present work indicates a three phase formation instead of two as discussed in previous works. This work has been carried out in collaboration with Tuli De.

Asis Chattopadhyay

Outlier detection through Independent Components for non-Gaussian data

Observations lying "far away" from the main part of a data set and probably not following the assumed model may be termed as outliers. It is clear from the definition of outlier that significant presence of outlying observations may lead to erroneous results, which in turn affects the statistical analysis of the data. So a very natural consequence of the above phenomenon will lead to the identification of outliers and eliminate them from the data set. Standard outlier detection techniques often fail to detect true outliers for massive, high dimensional and non-Gaussian data sets. Several authors proposed different methods for this purpose. Filzmoser P., et al. (2008) proposed an algorithm using the properties of Principal Components to identify outliers in the transformed space. In the present work, this method is modified by using Independent Components, which is necessary for dealing with non-Gaussian data. Primarily the dimension has been reduced through Independent Component. Analysis and the proposed method has been applied in the reduced space in order to identify the outliers. The utility of the proposed method has been verified through massive, non-Gaussian simulated data as well as real astronomical data related to Globular clusters of the Galaxy NGC 5128. This work has been carried out in collaboration with Saptarshi Mondal.

Surajit Chattopadhyay

Generalized second law of thermodynamics in QCD ghost $f(G)$ gravity

Considering power-law for scale factor in a flat FRW universe, we report a reconstruction scheme for $f(G)$ gravity based on QCD ghost dark energy. We reconstruct the effective equation of state parameter and observed "quintessence" behaviour of the equation of state parameter. Furthermore, considering dynamical apparent horizon as the enveloping horizon of the universe, we observe that the generalized second law of thermodynamics is valid for this reconstructed $f(G)$ gravity.

New holographic reconstruction of scalar field dark energy models in the framework of chameleon Brans-Dicke cosmology

Motivated by the work of Yang, et al. (2011), we report a study on the New Holographic Dark Energy (NHDE) model with energy density given by $\rho_D = \frac{3\phi^2}{4\omega}(\mu H^2 + \nu \dot{H})$ in the framework of chameleon Brans-Dicke cosmology. We study a correspondence between the quintessence, the DBI-essence and the tachyon scalar field models with the NHDE model. Deriving an expression of the Hubble parameter H, and accordingly, ρ_D in the context of Brans-Dicke chameleon cosmology, we reconstruct the potentials and dynamics for these scalar field models. Furthermore, we examine the stability for the obtained solutions of the crossing of the phantom divide under a quantum correction of massless conformally-invariant fields, and we see that quantum correction could be small when the phantom crossing occurs and the obtained solutions of the phantom crossing could be stable under the quantum correction. It has also been noted that the potential increases as the matter-chameleon coupling gets stronger with the evolution of the universe. This work has been done in collaboration with Antonio Pasqua, and Martiros Khurshudyan.

Tanuka Chattopadhyay and Asis Chattopadhyay

Cosmic history of the integrated galactic stellar initial mass function: A simulation study

Theoretical and indirect observational evidence suggests that the stellar initial mass function (IMF) increases with redshift. On the other hand, star formation rates (SFRs) may be as high as $100 M_{\odot}\ yr^{-1}$ in starburst galaxies. These may lead to the formation of massive clusters, hence massive stars, making the integrated galactic stellar initial mass function (IGIMF) top-heavy (i.e., the proportion of massive stars is higher than that of less massive stars). We investigate the joint effect of evolving the IMF and several measures of SFRs in dependence on the galaxy wide IMF. The resulting IGIMFs have slopes $\alpha_{2,IGIMF}$ in the high-mass regime, which is highly dependent on the minimum mass of the embedded cluster (Mecl,min), SFR, and mass-spectrum indices of embedded clusters (β). It is found that for $z \sim 02, \alpha_{2,IGIMF}$ becomes steeper (i.e., bottom-heavy), for $z \sim 24, \alpha_{2,IGIMF}$ becomes flatter (i.e., top-heavy), and from $z \sim 4$ onward, $\alpha_{2,IGIMF}$ again becomes steeper. The effects are faster for higher values of β $\alpha_{2,IGIMF}$, and also for higher values of $M_{ecl,min}$. All of these effects may be attributable to the joint effect of increasing the temperature of the ambient medium as well as varying the SFR with increasing redshift. This work has been done in collaboration with Tuli De, and Bharat Warlu.

Bhag Chand Chauhan

Computational holographic imaging using 2D-scalar wave

In this work, we study holography using computer simulations. We present a mathematical description of how one can produce and read a thin hologram using different kinds of waves, such as scalar (acoustic waves), vector (electromagnetic field, Maxwell-Proca fields, etc.). We construct a computer programme for the scalar wave in the two dimensional infra-space. For reading of the hologram, we use the Green's function formalism. With the help of computer simulations, we investigate the aberrations of image created by this procedure. We found a comma-like aberration in most of the cases studied. This work has been done in collaboration with Zoltan Batiz.

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 observed facts, this region is the highest seismic prone zone. In our previous work, we have shown 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 geothermal sites in Himachal Pradesh, the intensity and risk due to earthquake disaster can be made less detrimental.

Partha Chowdhury

Short-term periodicities in inter-planetary, geomagnetic and solar phenomena

In this work, we study the quasi-periodic variations of sunspot area/number, 10.7 cm solar radio flux, Average Photospheric Magnetic Flux, interplanetary magnetic field (Bz) and the geomagnetic activity index Ap during the ascending phase of the current solar cycle 24. We use both Lomb-Scargle periodogram and wavelet analysis technique, and find evidence for a multitude of quasi-periodic oscillations in all the data sets. In high frequency range (10 days to 100 days), both methods yield similar significance periodicities around 20 - 35 days and 45 - 60 days in all data sets. In the case of intermediate range, the significant periods were around 100 - 130 days, 140 - 170 days and 180 - 240 days. The Morlet wavelet power spectrum shows that all of the above mentioned periods are intermittent in nature. We find that the well-known "Rieger period" of (150 - 160 days) and near Rieger periods (130 - 190 days) are significant in both solar, inter-planetary magnetic field and geomagnetic activity data sets during cycle 24. The geomagnetic activity is the result of the solar wind-magnetosphere interaction. Thus, the variations in the detected periodicity in variety of solar, inter-planetary and geomagnetic indices could be helpful to improve our knowledge of the inter-relationship between various processes in the Sun-Earth-Heliosphere system. This work has been carried out in collaboration with D. P. Choudhary, S. Gosain, and Y. J. Moon.

Himadri Sekhar Das

Study of background star polarization and polarization efficiency of three selected Bok globules: CB56, CB60 and CB69

H. S. Das, in collaboration with A. Chakraborty, and D. Paul, has studied the polarization maps of three selected Bok globules CB56, CB60 and CB69 using a V-band data from a CCD imaging polarimeter. The aim of this work is to measure the optical polarization (p_v) of background field stars in order to determine the polarization efficiency, P_V/A_V. We find that the local magnetic field of the cloud CB56 is almost aligned with the galactic field, but not in CB60 and CB69. A trend of decreasing polarization efficiency with increasing extinction (A_V) is observed: It can be well represented by a power-law, $P_V/A_V \propto A_V^{-\alpha}$, where $\alpha = -0.56 \pm 0.36$, -0.59 ± 0.51 and -0.52 ± 0.49 for CB56, CB60 and CB69 respectively. This indicates that the linear polarization of the starlight due to aligned dust grains in these clouds is produced more efficiently in low extinction regions as compared to high obscured lines of sight.

Polarization of cosmic dust simulated with the rough spheroid model

H. S. Das, in collaboration with L. Kolokolova, O. Dubovik, T. Lapyonok, and P. Yang, has studied the light scattering properties of cosmic dust using rough spheroid model. Cosmic dust is a polydisperse mixture of irregular, often aggregated, particles. Previous attempts have tried to simulate polarimetric properties of this dust using aggregate dust models, but it has not been possible to consider particle sizes larger than a couple of microns due to limitations of computer memory and processing power. Attempts have also been made to replace aggregates by polydisperse regular particles (spheres, spheroids, cylinders), but those models could not consistently reproduce the observed photopolarimetric characteristics. In this study, we introduce the software package developed by Dubovik, et al. (2006) for modelling light scattering by a polydisperse mixture of randomly oriented smooth and rough spheroids of a variety of aspect ratios. The roughness of spheroids is defined by a normal distribution of the surface slopes, and its degree depends on the standard deviation of the distribution (which is zero for smooth surface and greater than zero for rough surface). The pre-calculated kernels in the software package allow for fast, accurate, and flexible modelling of different size and shape distributions. We find that the difference between smooth and rough particles increases with increasing effective size parameter, and affects mainly the value and position of the maximum polarization. Negative polarization was found to be typical only for silicate-like refractive indexes and only when the particles have size parameters within $2.5 - 25$. As an example, we make computations for rough spheroids that have a size distribution and composition typical for cometary dust. We find that a mixture of porous rough spheroids made of absorbing material compositionally similar to comet Halleys dust and solid silicate spheroids, dominated by particles of size parameter $5 < x < 20$, can reproduce angular and spectral characteristics of the brightness and polarization observed for cometary dust.

Sudipta Das

Cosmic acceleration in non-canonical scalar model - An interacting scenario

In this work, we study the dynamics of accelerating scenario within the framework of scalar field models possessing a non-canonical kinetic term. In this toy model, the scalar field is allowed to interact with the dark matter component through a source term. We assume a specific form for the coupling term and then study the dynamics of the scalar field having a constant equation of state parameter. We also carry out the dynamical system study of such interacting non-canonical scalar field models for power-law potentials for some physically relevant specific values of the model parameters. It has been found that only for two particular stable fixed points of the system, an accelerating solution is possible and the universe will settle down to a ΛCDM universe in future and thus, there is no future singularity in this model. This work has been done in collaboration with Abdulla Al Mamon

Ujjal Debnath

Reconstructing $f(R)$, $f(G)$, $f(T)$ and Einstein-Aether gravities from entropy-corrected (m, n) type Pilgrim dark energy

This work has described the ordinary holographic dark energy (HDE), (m, n) type holographic dark energy, entropy-corrected holographic dark energy (ECHDE) for logarithmic and power-law versions and Pilgrim dark energy (PDE) models. We introduce the (m, n) type Pilgrim dark energy and its entropy-corrected versions of logarithmic and power-law forms, i.e., (m, n) type LECPDE and PLECPDE models. The main motivation of the work is to reconstruct $f(R)$, $f(G)$, $f(T)$ and Einstein-Aether gravities from entropy-corrected (m, n) type Pilgrim dark energy (ECPDE). Also, we find the effective density and pressure for the $f(R)$, $f(G)$, $f(T)$ and Einstein-Aether gravities sectors respectively. These can be treated as effective dark energy. Assuming the power law solution of the scale factor, $a \sim t^{\delta}$, we can reconstruct the unknown functions of $f(R)$, $f(G)$, $f(T)$ and $F(K)$ of Einstein-Aether gravities from logarithmic and power-law corrected versions of ECPDE. Some cosmological implications of the reconstructed models have been analyzed.

Accretion and evaporation of modified Hayward black hole

The accretion phenomena of general kind of fluid onto the most general static spherically symmetric static black hole has been investigated. The accretion of fluid flow around the regular modified Hayward black hole have been analyzed and we then find the critical point, fluid 4 velocity and velocity of sound during accretion process. Also, the nature of the dynamical mass of black hole, during accretion of fluid flow and taking into consideration of Hawking radiation from black hole, i.e., evaporation of black hole, have been analyzed. For normal matter and quintessence type of dark energy accretion, the black hole mass always increases and for phantom accretion, the black hole mass decreases.

S. Dev

Near maximal atmospheric neutrino mixing in neutrino mass models with two texture zeros

The implications of a large value of the effective Majorana neutrino mass for a class of two texture zero neutrino mass matrices have been studied in the flavour basis. It is found that these textures predict near maximal atmospheric neutrino mixing angle in the limit of large effective Majorana neutrino mass. It is noted that this prediction is independent of the values of solar and reactor neutrino mixing angles. We present the symmetry realization of these textures using the discrete cyclic group Z_3. It is found that the texture zeros realised in this work remain stable under renormalization group running of the neutrino mass matrix from the seesaw scale to the electro-weak scale, at one loop level. This work has been carried out in collaboration with Radha Raman Gautam, Lal Singh, and Manmohan Gupta.

Charged lepton corrections to scaling neutrino mixing

Assuming Majorana nature of neutrinos, a general expression for the charged lepton corrections to scaling neutrino mixing has been obtained in the context of three flavour neutrino oscillations. Non-zero value of the reactor mixing angle is nicely accommodated. It is noted that scaling in the effective neutrino mass matrix is equivalent to the presence of two vanishing minors corresponding to first row elements of the effective neutrino mass matrix. A value of reactor mixing angle, which is fairly close to the currently measured best fit is predicted for charged lepton corrections of the order of the Cabbibo angle. We also present symmetry realization of such texture structures in the framework of type-I seesaw mechanism with non-diagonal charged lepton mass matrix using discrete Abelian flavour symmetry. This work has been done in collaboration with Radha Raman Gautam, and Lal singh.

Jishnu Dey and Mira Dey

A strange star scenario for the formation of eccentric millisecond pulsar/helium white dwarf binaries

According to the recycling scenario, millisecond pulsars (MSPs) have evolved from low-mass X-ray binaries (LMXBs). Their orbits are expected to be circular due to tidal interactions during binary evolution, as observed in most binary MSPs. There are some peculiar systems that do not fit this picture. Three recent examples are the PSRs J2234+06, J1946+3417, and J1950+2414, all of which are MSPs in eccentric orbits but with mass functions compatible with expected He white dwarf (WD) companions. It has been suggested that these MSPs may have formed from delayed accretion-induced collapse of massive WDs, or the eccentricity may be induced by dynamical interaction between the binary and a circum-binary disk. Assuming that the core density of accreting neutron stars (NSs) in LMXBs may reach the density of quark deconfinement, which can lead to phase transition from NSs to strange quark stars, we show that the resultant MSPs are likely to have an eccentric orbit, due to the sudden loss of the gravitational mass of the NS during the transition. The eccentricities can be reproduced with a reasonable estimate of the mass loss. This scenario might also account for the formation of the youngest known X-ray binary Cir X–1, which also possesses a low-field compact star in an eccentric orbit. This work has been done in collaboration with Long Jiang, and Xiang- Dong Li.

Broja Gopal Dutta

Lag variability associated with quasi-periodic oscillations in GX 339-4 during outbursts

The black hole transient GX 339-4 has exhibited four outbursts at 2 - 3 years intervals. We have analyzed RXTE/PCA data of this source for the 2002/2003, 2004, 2007 and 2010 outbursts. The power density spectrum exhibits quasi-periodic oscillations (QPO) whose frequency varies from 0.2 Hz to 8 Hz in addition to band-limited noise. We measure the time/phase lags between soft (2 - 5 keV) and hard (5 - 13 keV) photons at the QPO centroid frequency and at the continuum noise. We find that hard phase/time lags for both centroid frequency, and continuum monotonically increasing from 0.01 at 0.2 Hz to 0.68 at 8 Hz. This correlation appears to be same for all outbursts. The single correlation picture of phase/time lag for all four outbursts suggests a general evolution scenario of the QPOs during the outbursts. We discuss the implications of these results on the basis of possible accretion models. This work has been done in collaboration with Tomaso Belloni, and Sara Motta.

Sunandan Gangopadhyay

Non-commutativity from exact renormalization group dualities

We demonstrate, first, the construction of dualities using the exact renormalization group approach, and second, that spatial non-commutativity can emerge as such a duality. This is done in a simple quantum mechanical setting that establishes an exact duality between the commutative and non-commutative quantum Hall systems with harmonic interactions. It is also demonstrated that this link can be understood as a blocking (coarse graining) transformation in time that relates commutative and non-commutative degrees of freedom. This work has been carried out in collaboration with F.G. Scholtz.

Remnant mass and entropy of black holes and modified uncertainty principle

In this work, we study the thermodynamics of black holes using a generalized uncertainty principle (GUP) with a correction term linear order in the momentum uncertainty. The mass-temperature relation and heat capacity are calculated from which critical and remnant masses are obtained. The results are exact and are found to be identical. The entropy expression gives the famous area theorem upto leading order corrections from GUP. In particular, the linear order term in GUP leads to a $\sqrt{A}$ correction to the area theorem. Finally, the area theorem can be expressed in terms of a new variable termed as reduced horizon area only when the calculation is done to the next higher order correction from GUP. This work has been carried out in collaboration with Abhijit Dutta.

Sushant G. Ghosh

Rotating Ayón-Beato-García black hole as a particle accelerator

We study the collision of two particles with equal masses moving in the equatorial plane near the horizon of the rotating regular Ayón-Beato-García (ABG) black hole (BH), and calculate the centre-of-mass (CM) energy for the colliding particles for both extremal and non-extremal cases. It turns out that CM energy depends not only on rotation parameter a, but also on charge Q. Particularly for the extremal rotating regular ABG BH, the CM energy of two colliding particles could be arbitrarily high for the critical angular momentum of particles. Furthermore, we also show that, for a non-extremal BH, there exists a finite upper limit of CM energy, which changes with charge Q. A comparison with Kerr and Kerr-Newman black holes is included. This work has been carried out in collaboration with Pankaj Sheoran, and Muhammed Amir.

Shadow of five-dimensional rotating Myers-Perry black hole

A black hole casts a shadow as an optical appearance because of its strong gravitational field. We study the shadow cast by the five-dimensional Myers-Perry black hole with equal rotation parameters. We demonstrate that the null geodesic equation can be integrated, which provides an opportunity to investigate the shadow cast by a black hole. The shadow of a black hole is found to be a dark zone covered by a deformed circle. Interestingly, the shapes of the black hole shadow are more distorted and the size decreases for larger black hole spins. Interestingly, it turns out that, for fixed values of the rotation parameter, the shadow is slightly smaller and less deformed than for its four-dimensional Kerr black hole counterpart. Further, the shadow of the five-dimensional Kerr black hole is concentric deformed circles. The effect of the rotation parameter on the shape and size of a naked singularity shadow is also analyzed. This work has been carried out in collaboration with Uma Papnoi, Farruh Atamurotov, and Bobomurat Ahmedov.

Rupjyoti Gogoi

The dust content and radiation fields of sample of galaxies in the ELAIS-N1 field

The mid-IR colours (F_8/F_{24}) of galaxies together with their IR-UV luminosity correlations can be used to get some insight into the relative abundance of the different dust grain populations present in them. The ELAIS-N1 field contains thousands of galaxies, which do not have optical spectra but have been observed in the mid-IR by *Spitzer* and UV by *GALEX* making it ideal for these studies. As part of this work, we have selected a sample of galaxies, from the ELAIS-N1 field, which have photometric observations in the MIR and UV as well as photometric redshifts from the SDSS database. We put the constraint that the redshifts are ≤ 0.1, thereby giving a total of 309 galaxies. We find that the majority of the galaxies, in the sample are PAH dominated due to their high MIR flux ratio. We also find a reasonable correlation between the mid-IR and the UV luminosities out of which the mid-IR emission from PAHs at 8 μm is marginally better correlated than the 24 μm VSG emission with the UV luminosities. However, if we divide the sample based on their F_8/F_{24} ratios which is also an indicator of metallicity, the MIR-UV correlation seems to increase with the F_8/F_{24} ratio. But the MIR-UV correlations are not very different for the PAHs and the VSG population within the individual metallicity groups. This work has been done in collaboration with Ranjeev Misra, Ranjan Gupta, et al.

Sarbari Guha

Dissipative cylindrical collapse of charged anisotropic fluid

We study the dynamics of a cylindrical column of anisotropic charged fluid, which is experiencing dissipation in the form of heat flow, free-streaming radiation, and shearing viscosity, undergoing gravitational collapse. We calculate the Einstein-Maxwell field equations, and using the Darmois junction conditions, match the interior non-static cylindrically symmetric spacetime with the exterior anisotropic, charged, cylindrically symmetric spacetime. The behaviour of the density, pressure and luminosity of the collapsing matter has been analyzed. From the dynamical equations, the effect of charge and dissipative quantities over the cylindrical collapse are studied. Finally, we derive the solutions for the collapsing matter, which is valid during the later stages of collapse and have discussed the significance from a physical standpoint. This work has been done in collaboration with Ranajoy Banerji.

Sk. Monowar Hossein and Md. Mehedi Kalam

Analyticle model of strange star in the low-mass X-ray binary 4U 1820-30

In this work, we propose a model for a realistic strange star under Tolman VII metric (Tolman, 1939). Here, the field equations are reduced to a system of three algebraic equations for anisotropic pressure. Mass, central density and surface density of strange star in the low-mass X-ray binary 4U 1820-30 are matched with the observational data. Strange materials clearly satisfy the stability condition (i.e., sound velocities < 1) and TOV equation. Here also, the surface redshift of the star is found to be within a reasonable limit. This work has been done in collaboration with Farook Rahaman, Sajahan Molla and Md. Abdul Kayum Jafry.

Galactic rotation curves and strange quark matter with observational constraints

We 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. Significantly, we show 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 carried out in collaboration with Farook Rahman, and J. Naskar.

Ngangbam Ibohal and K. Yogindro Singh

Schwarzschild black hole in dark energy background

An exact solution of Einstein's field equations describing the Schwarzschild black hole in dark energy background having the equation of state parameter $w = -\frac{1}{2}$ has been proposed. It is also regarded as a solution that the Schwarzschild black hole is embedded into the dark energy space producing Schwarzschild-dark energy black hole. It is found that the spacetime geometry of this solution is non-vacuum Petrov type D. The energy conditions (like weak, strong and dominant) for the energy-momentum tensor have been studied. It is found that the energy-momentum tensor violates the strong energy condition due to the negative pressure leading to a repulsive gravitational force of the matter field in the spacetime. It is shown that the time-like vector field for an observer is expanding, accelerating, shearing and non-rotating. The surface gravity and the area of the horizons also have been investigated. This work has been done in collaboration with Ngangbam Ishwarchandra.

Reissner-Nordstrom black hole in dark energy background

A stationary solution of Einstein's field equations describing Reissner-Nordstrom black hole in dark energy background with the equation of state parameter $w = -\frac{1}{2}$ has been proposed. The spacetime geometry of Reissner-Nordstrom dark energy solution is found to be Petrov type D in the classification. It is also shown that the embedded spacetime possesses an energy-momentum tensor of the electromagnetic field interacting with the dark energy having negative pressure. It is also found that the energy-momentum tensor for dark energy violates the strong energy condition due to the negative pressure, whereas that of the electromagnetic field obeys the strong energy condition. It is shown that the time-like vector field for an observer is expanding, accelerating, shearing and non-rotating. The characteristic property of relativistic dark energy based on the de Sitter solution is also discussed This works has been done in collaboration with Ngangbam Ishwarchandra.

Naseer Bhat Iqbal

Search for astrophysical results with LIGO from the science runs S1 to S5

The gravitational wave detectors, especially LIGO has attained its design sensitivity, and up gradation has virtually reached near the completion. The gravitational wave search is in progress and hope-fully result will be possible in due course of time. We discuss the recent attempts to detect various classes of signals, which include unmodelled sub-second burst of gravitational radiation from core collapse supernoval and γ-ray burst engine. A stochastic background of gravitational waves of cosmological origin would provide a new idea about early universe. We discuss current attempts to detect gravitational waves from these sources, and know about future prospectus of these searches. This work has been done in collaboration with S. Monga, and Z. Shah.

The effect of X-ray irradiation on the time dependent behaviour of accretion discs with stochastic perturbations

The X-rays emitted by the inner regions of the accretion disk induces structural changes in the outer regions of the disk. We study how the effective temperature and hence, the corresponding spectrum of the disk is altered by the stochastic perturbations in the outer regions. We use a time dependent global hydrodynamic code to study the variations in the effective temperature of the disk to a sinusoidal accretion rate perturbations introduced at different radii, and with different time periods. To quantify the results, we calculate the root mean square effective temperature at different radii and also the root mean square flux at different frequencies. This work has been done in collaboration with M. Bari, Ranjeev Misra, and N. Ahmad.

Deepak Jain and Sanjay Jhingan

Testing the consistency between cosmological measurements of distance and age

We present a model independent method to test the consistency between cosmological measurements of distance and age, assuming the distance duality relation. We use type Ia supernovae, baryon acoustic oscillations, and observational Hubble data, to reconstruct the luminosity distance $D_L(z)$, the angle averaged distance $D_V(z)$ and the Hubble rate $H(z)$, using Gaussian processes regression technique. We obtain estimate of the distance duality relation in the redshift range $0.1 < z < 0.73$, and we find no evidence for inconsistency between the data sets used. This work has been carried out in collaboration with Remya Nair.

Kanti Jotania

Exact solutions in (2+1)-dimensional anti-de Sitter spacetime admitting a linear or non-linear equation of state

Gravitational analysis in lower dimensions has become a field of active research interest ever since Bañados, Teitelboim and Zanelli (BTZ, 1992) proved the existence of a black hole solution in $(2+1)$ dimensions. The BTZ metric has inspired many investigators to develop and analyze circularly symmetric stellar models, which can be matched to the exterior BTZ metric. We obtain two new classes of solutions for a $(2+1)$-dimensional anisotropic star in anti-de Sitter background spacetime by assuming that the equation of state (EOS) describing the material composition of the star could either be linear or non-linear in nature. By matching the interior solution to the BTZ exterior metric with zero spin, we demonstrate that the solutions provided here are regular and well-behaved at the stellar interior. This work has been done in collaboration with Ayan Banerjee, Farook Rahaman, et al.

Nagendra Kumar

Damping of linear non-adiabatic MHD waves in a flowing prominence medium

Nagendra Kumar and collaborators (A. Kumar, H. Sikka, and P. Kumar) study the effect of shear flow on the time damping of linear non-adiabatic magnetoacoustic waves in a solar prominence. They consider a homogeneous, isothermal, and unbounded medium permeated by a uniform magnetic field. The adiabaticity is removed by including the optically thin radiative losses, thermal conduction, and heating term in energy equation. They present a local theory of MHD waves to obtain a dispersion relation. The dispersion relation is solved numerically to study the time damping of these waves. It is found that flow influences the damping time and damping per period of both the slow and fast waves significantly. Damping time and damping per period of slow waves are very much higher than the damping time and damping per period of fast waves.

Suresh Kumar

Observational constraints on variable equation of state parameters of dark matter and dark energy after Planck

In this work, we study a cosmological model in general relativity within the framework of spatially flat Friedmann-Robertson-Walker spacetime filled with ordinary matter (baryonic), radiation, dark matter and dark energy, where the latter two components are described by Chevallier-Polarski-Linder equation of state parameters. We utilize the observational data sets from SNLS3, BAO and Planck+WMAP9+WiggleZ measurements of matter power spectrum to constrain the model parameters, and find that the current observational data offer tight constraints on the equation of state parameter of dark matter. We consider the perturbations and study the behaviour of dark matter by observing its effects on CMB and matter power spectra. We find that the current observational data favour the cold dark matter scenario with the cosmological constant type dark energy at the present epoch. This work has been done in collaboratiion with Lixin Xu.

Probing the matter and dark energy sources in a viable Big Rip model of the Universe

Chevallier-Polarski-Linder (CPL) parametrization for the equation of state of dark energy in terms of cosmic redshift or scale factor have been frequently studied in the literature. In this work, we consider cosmic time based CPL parametrization for the equation of state parameter of the effective cosmic fluid that fills the fabric of spatially flat and homogeneous Robertson-Walker spacetime. The model exhibits two worthy features: (i) It fits the observational data from the latest $H(z)$ and Union 2.1 SN Ia compilations matching the success of ΛCDM model. (ii) It describes the evolution of the Universe from the matter-dominated phase to the recent accelerating phase similar to the ΛCDM model, but leads to Big Rip end of the Universe contrary to the everlasting de Sitter expansion in the model. We investigate the matter and dark energy sources in the model, in particular, behaviour of the dynamical dark energy responsible for the Big Rip end of Universe

V.C. Kuriakose

Late-time evolution of Dirac field around Schwarzschild-quintessence black hole

The late-time evolution of Dirac field around spherically symmetric black hole surrounded by quintessece is studied numerically. Our results show that for lower values of the quintessence state parameter ε, Dirac field decays as power-law tail but with a slower decay rate than the corresponding Schwarzschild case. But for $\varepsilon < -1/3$, all the l -poles of the Dirac field give up the power-law decay form and relax to a constant residual field at asymptotically late-times. The value of this residual field for which the field settles down varies on different surfaces. It has the lowest value on the black hole event horizon, increases as the radial distance increases and maximizes on the cosmological horizon. This work has been done in collaboration with Nijo Varghese.

A unified thermodynamic picture of Horava-Lifshitz black hole in arbitrary spacetime.

In this work, we analyze the complete thermodynamic and phase transition phenomena of a black hole solution in Horava-Lifshitz gravity in arbitrary spacetime. Nature of phase transition is studied using geometro-thermodynamic and Ehrenfests scheme of standard thermodynamics. We analytically check the Ehrenfests equations near the critical point, which is the point of divergence in the heat capacity. Our analysis revels that this black hole exhibits a second order phase transition. This work has been done in collaboration with Jishnu Suresh, and T. Tharanath.

Badam Singh Kushvah

Geometry of halo and Lissajous orbits in the circular restricted three-body problem with drag force

In this work, we determine the effect of radiation pressure, Poynting-Robertson drag and solar wind drag on the Sun-(Earth-Moon) restricted three body problem. Here, we take the Sun as a larger primary, and Earth+Moon as a smaller primary. With the help of the perturbation technique, we find the Lagrangian points, and see that the collinear points deviate from the axis joining the primaries, whereas the triangular points remain unchanged in their configuration. We also find that Lagrangian points move towards the Sun when radiation pressure increases. We also analyse the stability of the triangular equilibrium points and find that they are unstable because of the drag forces. Moreover, we compute the halo orbits in the third-order approximation using Lindstedt-Poincaré method and find the effect of the drag forces. According to this prevalence, the Sun-(Earth-Moon) model is used to design the trajectory for spacecraft travelling under the drag forces. This work has been done in collaboration with Ashok Kumar Pal.

Manzoor A. Malik

Joint Planck and WMAP assessment of low CMB multipoles

We investigate the lack of power in the CMB temperature anisotropies at large angular scales (low-l), as has been confirmed by the recent Planck data extending upto $l = 40$. Features in the primordial power spectrum (PPS) motivated by the early universe physics have been the most common solution to address this problem. In this work, we follow this approach and considered a set of PPS, which have features and constrain the parameters of those using WMAP 9 year and Planck data employing Markov-Chain Monte Carlo (MCMC) analysis. The prominent feature of all the models of PPS, that considered is an infra-red cut off, which leads to suppression of power at large angular scales. We consider models of PPS with maximum three extra parameters and used Akaike information criterion (AIC) and Bayesian information criterion (BIC) of model selection to compare the models. For most models, we find good constraints for the cut off scale; however, for other parameters their constraints are not that good. Also sharp cut off model gives best likelihood value for the WMAP 9 year data, but is as good as power law model according to AIC. For the joint WMAP 9 + Planck data set, Starobinsky model is slightly preferred by AIC, which is also able to produce CMB power suppression up to $l = 30$ to some extent. This work has been done in collaboration with Asif Iqbal, Jayanti Prasad, and Tarun Souradeep.

Soma Mandal

Energy dependence of r.m.s. amplitude of low frequency noise and kHz quasi-periodic oscillations in 4U 1608-52

The neutron star low mass X-ray binary 4U 1608-52 is known to show kHz QPOs as well as low frequency broad band noise. The energy dependence of the fractional r.m.s. of these variations reflect the underlying radiative mechanism responsible for the phenomena. In this work, we compute the energy dependence for 26 instances of kHz QPO observed by RXTE. We typically find as reported before, that the r.m.s. increases with energy at the slope of ~ 0.5. This indicates that the variation is in the hot thermal Comptonization component and in particular, the QPO is likely to be driven by variation in the thermal heating rate of the hot plasma. For the same data, we compute the energy dependent r.m.s. variability of the low frequency noise component by considering light curves binned at 10 sec. In contrast to the behaviour seen for the kHz QPO, the energy dependence is nearly flat, i.e., with slope ~ 0. This indicates that the driver here may be the soft photon source. Thus, the radiative mechanism driving the low frequency noise and the high frequency QPO are different in nature. This is against a simple resonance model, where the QPO is simply a resonance at a particular high frequency which amplifies the underlying noise. Alternatively, if the QPO is a resonance, then the noise at kHz frequencies is of different origin that observed at low frequencies. This work has been done in collaboration with Ranjeev Misra.

Irom Ablu Meitei

Quantum non-thermal radiation of non-stationary rotating de Sitter cosmological model

Using the Hamilton-Jacobi method, we carry out a study of quantum non-thermal radiation of non-stationary rotating de Sitter cosmological model. We show that there exist seas of positive and negative energy states in the vicinity of the cosmological event horizon and also a forbidden energy gap between two seas. The forbidden energy gap vanishes on the surface of the cosmological event horizon so that the positive and negative energy levels overlap. The width of the forbidden energy gap and the energy of the particle at the cosmological event horizon are found to depend on the cosmological constant, the rotation parameter, positions of the particle and the cosmological event horizon, angular momentum of the particle, evaporation rate, and shape of the cosmological event horizon. The tunneling probability of the emitted particles constituting Hawking radiation is also deduced for stationary non-rotating de Sitter cosmological model, and the standard Hawking temperature is recovered. This work has been done in collaboration with T. Ibungochouba Singh, and K. Yugindro Singh.

Hawking radiation and entropy of Kerr-Newman black hole

Using the Hamilton-Jacobi method beyond semi-classical approximation, we investigate the entropy correction of Kerr-Newman black hole. To get the entropy correction, the inverse of the sum of square of event horizon (r_+) and the square of rotational parameter (a) of the black hole is taken as the proportionality parameter for quantum corrections of the action I_i to the semi-classical action I_0. It has been shown that as quantum effects are taken into account the corrections to the Bekenstein-Hawking entropy of the stationary black hole include a logarithmic term and an inverse area term beyond the semi-classical approximation. This work has been done in collaboration with T. Ibungochouba Singh, and K. Yugindro Singh.

Pradip Mukherjee

General algorithm for non-relativistic diffeomorphism invariance

An algorithmic approach towards the formulation of non-relativistic diffeomorphism invariance has been developed which involves both matter and gauge fields. A step by step procedure has been provided which can accommodate all types of (Abelian) gauge interaction. The algorithm is applied to the problem of a two dimensional electron moving under an external field and also under the Chern-Simons dynamics. This work has been carried out in collaboration with R. Banerjee, and A Mitra.

Localization of the Galilean symmetry and dynamical realization of Newton-Cartan geometry

Newtonian gravity was formulated as a geometrodynamic theory as far back in 1930s by Elie Cartan, in what is named aptly as Newton-Cartan spacetime. Though there are several approaches of realizing the algebraic structure of the Newton-Cartan geometry from a contraction of the relativistic results, a dynamical (field theoretic) realization of it is lacking. In this work, we present such a realization from the localisation of the Galilean symmetry of non-relativistic matter field theories. This work has been done in collaboration with R. Banerjee, and A. Mitra.

Hemwati Nandan

Geodesic motion in a charged 2D stringy black hole spacetime

We study the time like geodesics and geodesic deviation for a two-dimensional stringy black hole spacetime in Schwarzschild gauge. We analyze the properties of effective potential along with the structure of the possible orbits for test particles with different settings of black hole parameters. The exactly solvable geodesic deviation equation is used to obtain corresponding deviation vector. The nature of deviation and tidal force is also examined in view of the behaviour of corresponding deviation vector. The results are also compared with another two-dimensional stringy blackhole spacetime. This work has been done in collaboration with Rashmi Uniyal, and K. D. Purohit.

Geodesic motion in Schwarzschild spacetime surrounded by quintessence

We study the time-like geodesic congruences, in the spacetime geometry of a Schwarzschild black hole surrounded by quintessence. The nature of effective potential along with the structure of the possible orbits for test particles in view of the different values of quintessence parameter are analysed in detail. An increase in quintessence parameter is seen to set the particles from further distance into motion around black hole. The effect of quintessence parameter is investigated analytically wherever possible, otherwise we perform the numerical analysis to probe the structure of possible orbits. It is observed that there exist a number of different possible orbits for a test particle in case of non-radial geodesics, such as circular (stable as well as unstable) bound orbits, radially plunge and fly-by orbits, whereas no bound orbits exist in case of radial geodesics. This work has been done in collaboration with Rashmi Uniyal, N. Chandrachani Devi, and K. D. Purohit.

P.N. Pandita

Invisible decays of low mass Higgs-Bosons in super-symmetric models

The discovery of a 126 GeV Higgs like scalar at the LHC along with the non-observation of the super-symmetric particles, has in turn lead to constraining various super-symmetric models through the Higgs data. We consider the case of both the minimal super-symmetric standard model (MSSM), as well its extension containing an additional chiral singlet superfield, the next-to-minimal or non-minimal super-symmetric standard model (NMSSM). In case of the MSSM, we consider $H \approx 126$ GeV and $h \approx 98$ GeV, known as the non-decoupling regime, whereas in case of the NMSSM, $h_2 \approx 126$ GeV, with m_{h_1} and m_{a_1} varying depending on the parameter space. We find that in case of the MSSM with universal boundary conditions at the GUT scale, it is not possible to have light neutralinos leading to the decay channel $H \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0$. The invisible decay mode is allowed in case of certain $SO(10)$ and E_6 grand unified models with large representations and non-universal gaugino masses at the GUT scale. In case of the NMSSM, for the parameter space considered, it is possible to have the invisible decay channel with universal gaugino masses at the GUT scale. We , furthermore, consider the most general case, with M_1 and M_2 as independent parameters for both MSSM and NMSSM. We isolate the regions in parameter space in both cases, where the second lightest Higgs-Boson has a mass of 126 GeV and then concentrate on the invisible decay of Higgs to lighter neutralinos. The other non-standard decay mode of the Higgs is also considered in detail. The invisible Higgs branching ratio being constrained by the LHC results, we find that in this case with the second lightest Higgs being the 126 GeV state, more data from the LHC is required to constrain the neutralino parameter space, compared to the case when the lightest Higgs-Boson is the 126 GeV state. This work has been done in collaboration with Monalisa Patra.

Amit Pathak

Relationship between X-ray spectral index and X-ray Eddington ratio for Mrk 335 and Ark 564

We present a comprehensive flux-resolved spectral analysis of the bright narrow-line Seyfert 1 AGNs, Mrk 335 and Ark 564 using observations by *XMM–Newton* satellite. The mean and the flux-resolved spectra are fitted by an empirical model consisting of two Comptonization components, one for the low-energy soft excess and the other for the high-energy power law. A broad iron line and a couple of low-energy edges are required to explain the spectra. For Mrk 335, the 0.3 – 10 keV luminosity relative to the Eddington value, L_X/L_{Edd}, varied from 0.002 to 0.06. The index variation can be empirically described as $\Gamma = 0.6 \log_{10} L_X/L_{Edd} + 3.0$ for $0.005 < L_X/L_{Edd} < 0.04$. At $L_X/L_{Edd} \sim 0.04$, the spectral index changes and then continues to follow $\Gamma = 0.6 \log_{10} L_X/L_{Edd} + 2.7$, i.e., on a parallel track. We confirm that the result is independent of the specific spectral model used by fitting the data in the 3 – 10 keV band by only a power-law and an iron line. For Ark 564, the index variation can be empirically described as $\Gamma = 0.2 \log_{10} L_X/L_{Edd} + 2.7$ with a significantly large scatter as compared to Mrk 335. Our results indicate that for Mrk 335, there may be accretion disc geometry changes, which lead to different parallel tracks. These changes could be related to structural changes in the corona or enhanced reflection at high flux levels. There does not seem to be any homogeneous or universal relationship for the X-ray index and luminosity for different AGNs or even for the same AGN. This work has been done in collaboration with R. Sarma, S. Tripathi, et al.

HST/COS detection of a Ne VIII absorber towards PG 1407+265: An unambiguous tracer of collisionally ionized hot gas?

We report the detection of Ne VIII in a $z_{abs} = 0.59961$ absorber towards the QSO PG1407+265 ($z_{em} = 0.94$). Besides Ne VIII, absorption from H I Lyman series lines (H I $\lambda1025 - \lambda915$), several other low (C II, N II, O II and S II), intermediate (C III, N III, N IV, O III, S IV and S V) and high (S VI, O VI and Ne VIII) ionization metal lines are detected. Disparity in the absorption line kinematics between different ions implies that the absorbing gas comprises of multiple ionization phases. The low and the intermediate ions (except S V) trace a compact (410 pc), metal-rich ($Z \sim Z_\odot$) and over-dense ($\log n_H \sim -2.6$) photoionized region that sustained star formation for a prolonged period. The high ions, Ne VIII and O VI, can be explained as arising in a low density ($-5.3 \leq \log n_H \leq -5.0$), metal-rich ($Z \geq Z_\odot$) and diffuse (∼180 kpc) photoionized gas. The S V, S VI and C IV (detected in the Faint Object Spectrograph (FOS) spectrum) require an intermediate photoionization phase with $-4.2 < \log n_H < -3.5$. Alternatively, a pure collisional ionization model, as used to explain the previous known Ne VIII absorbers, with $5.65 < \log T < 5.72$, can reproduce the S VI, O VI and Ne VIII column densities simultaneously in a single phase. However, even such models require an intermediate phase to reproduce any observable S V and/or C IV. Therefore, we conclude that when multiple phases are present, the presence of Ne VIII is not necessarily an unambiguous indication of collisionally ionized hot gas. This work has been done in collaboration with T. Hussain, S. Muzahid, et al.

Ninan Sajeeth Philip

Identification of specific patterns hidden in noisy data

Searching for hidden patterns of interest in noisy data is a very challenging problem in astronomy and biosciences. Due to the distortions made by noise, standard morphological analysis may not always detect them correctly. Usually, it may not be possible to model the noise adequately nor filter them out easily. In astronomy, gravity wave detection is such a challenging task. We consider a similar problem in human Electroencephalographic (EEG) signals produced by neurons in the brain. EEG signals are feeble electrical pulses produced by the intelligence stored in the neurons as they communicate with each other. The brain, despite its relatively small size, has comparable number of neurons as there are stars in a galaxy. All of these neurons are firing all the time, making it a massively parallel processing system. Much of this communication is not well understood; but, scientists have identified various regions in the brain that carries out different functions. For example, the visual image falling on the retina is carried to the visual cortex in the occipital lobe that is at the back of the brain, and neurons in this region fire in accordance with the visual input. Studies have shown that the electrical potential of these impulses are related to our cognitive capability and have named them as Event Related Potential (ERP). The ERP in the visual cortex is formed about 300 ms after seeing and has a negative going voltage, which is proportional to the cognitive intimacy to the subject. Since it is seen after 300 ms, it is named P300, and is widely used to study visual capabilities of the brain.

Though isolated ERPs are well defined, due to inherent noise in EEG signal, their identification is a non-trivial procedure. It has been known for long that spectral analysis is the best method to identify hidden information in signals. Of the different methods, wavelet based spectral analysis is more robust than Fourier analysis, because they preserve spatial information along with time resolution, making it easy to detect isolated events in the signal. It is showed that instead of directly using the wavelets, the use of the asymmetry properties of the wavelets can give more precise identification of the location of the interested pattern in a noisy signal. This technique is shown to perform better than other methods used for this purpose. We also work on feature identification challenges in time domain astronomy using the Catalina Real-time Transient Survey (CRTS) data. This work has been done in collaboration with Arun Kumar A., Vineet J. Samar, et al.

Photometric studies of astronomical candidates from Sloan Digital Sky Survey

This work mostly targets faint objects in surveys that are inaccessible to spectroscopic studies. In such situations, multi-colour photometric information can be used to predict the probable nature of the objects. It is demonstrated that this can be efficiently done using Machine Learning methods. Using this method, we could prepare a catalogue of about 2.4 million quasars, 3.5 million stars and a small number of unresolved galaxies from Sloan Digital Sky Survey (SDSS) Seventh Data Release (DR7). Observational confirmations from various surveys indicate that the reliability of these classifications are of the order of 98 and above. The catalogue and the algorithm are released under Creative Commons license. In a subsequent study, we are able to determine the photometric redshift of these objects reliably, and also authored a semi-automated pipeline for the CRTS spectroscopic follow-up studies. This work has been done in collaboration with Sheelu Abraham.

Anirudh Pradhan

Accelerating dark energy models of the universe in anisotropic Bianchi type spacetimes and recent observations

Motivated by the increasing evidence for the need of a geometry that resembles Bianchi morphology to explain the observed anisotropy in the WMAP data, we discuss some features of the Bianchi type universes in the presence of a fluid that wields an anisotropic equation of state (EoS) parameter in general relativity. Such models are of great interest in cosmology in favour of constructing more realistic models than FLRW models with maximally symmetric spatial geometry. Additionally, the interest in such models was promoted in recent years due to the debate that is going on in the analysis and interpretation of the WMAP data (2004, 2007, 2009), whether they need a Bianchi type morphology to be explained successfully. The LLC-WMAP data maps show seven axes well aligned with one another and the direction Virgo. For this reason, Bianchi models are important in the study of anisotropies. In the present work of Bianchi type I, II, III, V and VI0 spacetimes, we observe that the EoS for dark energy ω is found to be time dependent, and its existing range for derived models is in good agreement with the recent observations of SNe Ia data (2003), SNe Ia data with CMBR anisotropy and galaxy clustering statistics (2004) and latest combination of cosmological datasets coming from CMB anisotropies, luminosity distances of high redshift type Ia supernovae and galaxy clustering (2009). It has been suggested that the dark energy that explains the observed accelerating expansion of the universe may arise due to the contribution to the vacuum energy of the EoS in a time dependent background. The cosmological constant Λ is found to be a positive decreasing function of time and it approaches to a small positive value at late time (i.e., the present epoch), which is corroborated by results from recent type Ia supernovae observations. This work has been carried out in collaboration with B. Saha.

The whipped inflation in BIon system

Recently, a class of large field inflaton potentials has been identified which begins with a power law potentials. In this model, initially relative fast roll lasting until a few e-folds in the horizon transits to the slow roll part potential with low power. Here, a question arises regarding the origin of the whipped inflation in 4D universe? We find the answer in BIon system. A model is proposed that allows all parameters of this model to depend on the separation distance, tachyonic potential and wormholes between two branes in this system. These wormholes are formed due to collision between the spikes of brane and antibrane. We examine the whipped inflationary model against Planck and BICEP2 data and show that the model works. This work is done in collaboration with A. Sepehri, and S. Shoorvazi.

Farook Rahaman

Possible existence of wormholes in the central regions of halos

An earlier study has demonstrated the possible existence of wormholes in the outer regions of the galactic halo, based on the Navarro-Frenk-White (NFW) density profile. This work uses the Universal Rotation Curve (URC) dark matter model to obtain analogous results for the central parts of the halo. This result is an important compliment to the earlier result, thereby confirming the possible existence of wormholes in most of the spiral galaxies. This work has been done in collaboration with P. Salucci, P.K.F. Kuhfittig, et al.

Emergence and expansion of cosmic space in BIonic system

Recently, Padmanabhan [arXiv:1206.4916] argued that the expansion rate of the universe can be thought of as the emergence of space as cosmic time progresses, and is related to the difference between the surface degrees of freedom on the holographic horizon and the bulk degrees of freedom inside. The main question arises as to what is origin of emergence of space in 4D universe? We answer to this question in BIonic system. The BIon is a configuration in flat space of a D-brane and a parallel anti-D-brane connected by a thin shell wormhole with F-string charge. We propose a new model that allows all degrees of freedom inside and outside the universe, and are controlled by the evolutions of BIon in extra dimension and tend to degrees of freedom of black F-string in string theory or black M2-brane in M theory. This work has been done in collaboration with A. Sepehri, Anirudh Pradhan, and Iftikar Hossain Sardar.

S.R. Rajesh

Transition of accretion flow from Keplerian phase to advective phase as a dynamical system

A model for the transition of Keplerian accretion flow to advective phase is proposed. The advective fluid particle in the Keplerian accretion background is modelled using two phase hydrodynamics. The hydrodynamic equations for the advective phase is reduced to a non-linear dynamical system. For small fluctuation of advective nature for sufficiently small time, a linearised dynamical system in density and radial velocity is obtained. The fluctuation is found to be linearly growing for suitable choice of the values of free parameters. The linear growth is studied as a function of the angular Mach number of the background Keplerian accretion flow. The other parameters of the dynamical system are the radial Mach number of the Keplerian accretion flow, viscosity parameters and gas constants of the Keplerian phase as well as the advective phase and the angular velocity profile of the advective fluid particle. The location of the transition region between Keplerian accretion flow and advective accretion flow is parameterized by the radial Mach number and the angular Mach number of the Keplerian accretion flow. The Keplerian accretion flow is found to be linearly unstable against transition to advective phase only if the radial Mach number is greater than or of the order of 10^{-3}. Since radial velocity has no dynamical relevance in Keplerian accretion flow (radial Mach number is very small, and the radial velocity comes only as a drift velocity in the equation of continuity), this means that such a transition is possible only at much inner part of the accretion disc. Appreciable linear growth of the advective fluctuation is possible only if the viscosity parameter of the advective phase has high or intermediate value. This could severely restrict the plausible branches of global solution of the inner advective accretion disc. This work has been done in collaboration with S. B. Rakesh Chandran.

Shantanu Rastogi

Study of satellite retrieved CO2 and CH4 concentration over India

This work reports a study of spatial and temporal variations of columnar averaged concentration of CO2 and CH4 over India using SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) and Greenhouse gas Observing SATellite (GOSAT) data. Comparison of these data with the global view National Oceanic and Atmospheric Administration (NOAA), land data and also location specific flask data is made. The temporal variation in column averaged global CO2 is similar to that over India and it is also similar to the NOAA surface flask data and global view. The variation in NOAA surface CH4 is location dependent and its global view appears to vary seasonally in opposite phase with the column averaged CH4 values from satellites, reflecting the limited comparability of surface and column averaged data. Over India, the CO2 maximum is in May and minimum in August/September, while for CH4, the maximum is in September and minimum in February/March. The seasonal variation of CH4 over India is correlated with the eastern coastal rice cultivation. This work has been done in collaboration with R. P. Singh.

C.D. Ravikumar

Monitoring of radio-loud narrow-line Seyfert 1 galaxies in gamma-ray

Gamma-ray monitoring of five narrow line Seyfert-1 galaxies was carried out using the Large Area Telescope of the Fermi Gamma-ray Space Telescope. The average spectrum of three sources (PKS 1502+036, PKS 2004447 and SBS 0846+513) show good fits by a simple power-law, while the other two (1H 0323+342 and PMN J0948+002) show significant deviations from it. The analysis of the curvature of the latter suggests that the emission region is located inside the broad line region (BLR), while the primary mechanism of the gamma-ray emission is the inverse-Compton (IC) scattering of BLR photons occurring in the Klein-Nishina regime. This work has been done in collaboration with Vaidehi S. Paliya, and C.S. Stalin.

Long term optical variability of X-ray point sources in elliptical galaxies.

Taking a sample of four elliptical galaxies, we identify four optically varying counterparts of bright, off-nuclear X-ray sources. The optical variability implies the close association between X-ray and optical brightness of these sources. Further, the infrared colour inferred from the Spitzer telescope shows that all the four candidates are most likely background AGNs. This work has been carried out in collaboration with V. Jithesh, Ranjeev Misra, et al.

Saibal Ray

Anisotropic models for compact stars

In this work, we obtain an anisotropic analogue of Durgapal-Fuloria (1985) perfect fluid solution. The methodology consists of contraction of anisotropic factor Δ by the help of both metric potentials ν and λ. Here, we consider λ same as Durgapal-Fuloria (1985), whereas ν is that given by Lake (2003). The field equations are solved by the change of dependent variable method. The solutions set mathematically obtained are compared with the physical properties of some of the compact stars, strange star as well as white dwarf. It is observed that all the expected physical features are available related to stellar fluid distribution, which clearly indicate validity of the model. This work has been done in collaboration wtih S. K. Maurya, Y. K. Gupta, and B. Dayanandan.

Astronomer R.G. Chandra: In the light of his Anglo-American connection

In this work, we present some documents to reveal the longstanding relationship of Indian amateur astronomer R. G. Chandra with the British Astronomical Association and American Association of Variable Star Observers. This work has been done in collaboration with S. N. Biswas, and U. Mukhopadhyay.

Anirban Saha

Non-commutative quantum mechanics of simple matter systems interacting with circularly polarized gravitational waves

The response of a test particle, both for the free case and under the harmonic oscillator potential, to circularly polarized gravitational waves (GW) is investigated in a non-commutative (NC) quantum mechanical setting. An algebraic technique is then employed to solve the Hamiltonian of the system. The solutions, in both cases, show signatures of the coordinate non-commutativity. In the harmonic oscillator case, this NC effect plays a key role in altering the resonance point at which the system couples maximally with the GW. This feature, if observed in an experimental setting, will serve to determine the scale of spatial NC parameter. The applicability of this treatment and the relevance of these results to resonant bar detectors of GW are discussed. This work has been done in collaboration with Sunandan Gangopadhyay, and Swarup Saha.

Interaction of a circularly polarised gravitational wave with a charged particle in a static magnetic background

Interaction of a charged particle in a static magnetic background, i.e., a Landau system with circularly polarised gravitational wave (GW) is studied quantum mechanically in the long wavelength and low velocity limit. The rotating polarization vectors of the circularly polarized GW are employed to form a unique directional triad, which served as the coordinate axes. The Schrodinger equations for the system are cast in the form of a set of coupled linear differential equations. This system is solved by iterative technique. We compute the time-evolution of the position and momentum expectation values of the particle. The results show that the resonance behaviour obtained earlier by classical treatments of the system has a quantum analogue not only for the linearly polarized GW, but for circularly polarized GW as well. This work has been done in collaboration with Sunandan Gangopadhyay, and Swarup Saha.

Sanjay Kumar Sahay

A novel approach to distributed multi-class Support Vector Machine

The volume of data is constantly increasing and the classical algorithms used to analyze the data require huge amount of computational resources. It is apparent that to analyze large volume of data, computational requirement had to be distributed among several computers. Although substantial work has been done in developing distributed binary Support Vector Machine (SVM) algorithms and multi-class SVM algorithms individually, the field of multi-class distributed SVMs remains largely unexplored. Hence, in this work, we propose a novel algorithm that implements the SVM over a multi-class dataset, which is also efficient in a distributed environment (Hadoop). Similar to divide and conquer, the dataset is divided in two half recursively and thus, compute the optimal SVM during the training phase. Exploiting this structure effectively, we significantly reduce the prediction time. This algorithm shows better computation time during the prediction phase than the traditional sequential SVM methods (One vs. One, One vs. Rest) and out-performs them as the size of the dataset grows. This approach also classifies the data with higher accuracy than the traditional multi-class algorithms. This work has been carried out in collaboration with Aruna Govada, Shree S.S. Ranjani, and Aditi Viswanathan.

A novel modified apriori approach for web document clustering

The traditional apriori algorithm can be used for clustering the web documents based on the association technique of data mining. But this algorithm has several limitations due to repeated database scans and its weak association rule analysis. In modern world of large databases, efficiency of traditional apriori algorithm would reduce manifolds. Hence, we develop a modified apriori approach by cutting down the repeated database scans and improving association analysis of traditional apriori algorithm to cluster the web documents. Further, we improve those clusters by applying Fuzzy C-Means (FCM), K-Means and Vector Space Model (VSM) techniques separately. Experimental results show that this approach outperforms the traditional apriori algorithm in terms of database scan and improvement on association of analysis. We find that FCM is better than K-Means and VSM in terms of F-measure of clusters of different sizes. This work has been done in collaboration with Rajendra Kumar Roul, Saransh Varshneya, and Ashu Kalra.

Anjan Ananda Sen

Inflationary generalized Chaplygin gas and general dark energy in the light of the Planck and BICEP2 experiments

In this work, we study an inflationary scenario in the presence of Generalized Chaplygin Gas (GCG). We show that in Einstein gravity, GCG is not a suitable candidate for inflation; but in a five dimensional brane world scenario, it can work as a viable inflationary model. We calculate the relevant quantities such as n_s, r and A_s related to the primordial scalar and tensor fluctuations, and using their recent bounds from Planck and BICEP2 experiments, we constrain the model parameters as well as the five-dimensional Planck mass. But as a slow-roll inflationary model with a power-law type scalar primordial power spectrum, GCG as an inflationary model cannot resolve the tension between results from BICEP2 and Planck with a concordance ΛCDM Universe. We show that going beyond the concordance ΛCDM model and incorporating more general dark energy behaviour, this tension may be eased. We also obtain the constraints on the n_s and r and the GCG model parameters using Planck+WP+BICEP2 data considering the CPL dark energy behaviour. This work has been done in collaboration with Bikash R. Dinda, and Sumit Kumar.

Clustering GCG: A viable option for unified dark matter-dark energy?

We study the clustering Generalized Chaplygin Gas (GCG) as a possible candidate for dark matter-dark energy unification. The vanishing speed of sound ($c_s^2 = 0$) for the GCG fluid can be obtained by incorporating higher derivative operator in the original K-essence Lagrangian. The evolution of the density fluctuations in the GCG+Baryon fluid is studied in the linear regime. The observational constraints on the model are obtained using latest data from SNIa, $H(z)$, BAO and also for the $f\sigma_8$ measurements. The matter power spectra for the allowed parameter values are well behaved without any unphysical features. This work has been done in collaboration with Sumit Kumar.

Asoke Kumar Sen

A study of comet 78P/Gehrels by imaging polarimetry

Comet 78P/Gehrels was observed polarimetrically from the 2 m telescope at IUCAA Girawali Observatory (IGO) in India, and from the 0.8 m telescope at Haute-Provence Observatory (OHP) in France. The observations were carried out in three schedules: First in October 2011 (IGO), then in January 2012 (OHP) and lastly in February 2012 (IGO), when its phase angle was between 15.2° and 28.3°. In our knowledge, these are the first polarimetric measurements of the dust properties of Gehrels. Both broadband and narrow band cometary filters (to avoid gaseous contaminations) were used. Intensity images treated by a rotational gradient method, along with isophotes confirmed the presence of structures in the comet during the observation periods. In the polarization map, no significant difference in polarization values is noticed between the structures along the anti-solar direction and the surrounding coma, which suggests similar dust properties. After perihelion, in January, some jet activity was observed along the solar direction with higher positive polarization than the surrounding coma. The ejected particles seem to be relatively large and present with a low number density. The coma polarization measured in different apertures has been used to compare that obtained for other comets at similar phase angles. As expected, 78P/Gehrels is different from comet Hale-Bopp, but the comparison is not easy at phase angles lower than 35°. This work has been done in collaboration with S. Roy Choudhury, and E. Hadamcik.

Imaging polarimetry of the rotating Bok globule CB67

Polarimetric observations of about 50 stars located in a close vicinity of the Bok globule CB67 having significantly non-spherical shape and rapid rotation are performed. The data obtained are compared with the available observations of this globule at radio and sub-millimetre wavelengths as well as some theoretical calculations. It is found that the elongation and the rotation moment of CB67 are oriented rather perpendicular to the magnetic fields, which is unusual for Bok globules and is difficult to be explained from the theoretical point of view. This work has been done in collaboration with M.S. Prokopjeva, V.B. Il'in, et.al.

Ranjan Sharma

A class of conformally flat solutions for systems undergoing radiative gravitational collapse

Ranjan Sharma, in collaboration with Shyam Das, and Ramesh Tikekar, has examined the nature of collapse of a spherically symmetric matter distribution accompanied with radial heat flow formulated on a conformally flat background spacetime. In the formalism, the geometry of the background spacetime of the non-adiabatically collapsing matter is chosen to be conformal to that of the spacetime of Robertson-Walker metric so that the Weyl tensor vanishes identically. The RW spacetime is conformally flat and further characterized by the feature that its spatial sections are homogeneous. Accordingly, the spacetime coordinates of the collapsing configuration are such that the spatial geometry is conformally homogeneous and continues to be so throughout collapse. The pressure-isotropy relation in this approach is found to lead to two classes of solutions for the system. The conditions which ensure the smooth matching of the interior spacetime of the collapsing system, across its boundary, with the exterior spacetime of the radiating star lead to an equation governing its overall subsequent evolution. Physically viable collapsing models are constructed and examined by considering a couple of solutions of the temporal evolution equation. The pre-assigned metric form, in this work, brings out to attention the role of the curvature parameter k of RW spacetime explicitly in the evolution of the collapse in the presence of dissipation. The approach also indicates the inter-dependence between the inhomogeneities in the matter-density distribution and presence of dissipative processes during the evolution of the collapse. The nature of singularity is also analyzed.

Modified Finch and Skea stellar model compatible with observational data

Ranjan Sharma and his collaborators (D. M. Pandya, and V. O. Thomas) have developed a model for a class of static spherically symmetric anisotropic stars by generalizing the Finch and Skea (1989) ansatz for the metric potential g_{rr} of the associated spacetime. The anisotropic stellar model developed and studied by Sharma and Ratanpal (2013) has been shown to be a sub-class of the solutions provided in the model. Based on physical requirements, regularity conditions and stability, bounds on the model parameters were obtained. By systematically fixing values of the model parameters within the prescribed bound, it has been demonstrated that a large class of pulsars (e.g., 4U 1820-30, PSR J1903+327, 4U 1608-52, Vela X-1, PSR J1614-2230, SAX J1808.4-3658 and Her X-1) might be accommodated in the model. Though no a priori knowledge of the EOS of the material composition was necessary in the construction, physical features of the model turned out to be consistent with the stellar structures composed of exotic strange matter EOS.

Harinder Pal Singh

Morphology and metallicity of the SMC

A study of three-dimensional structure of the Small Magellanic Cloud (SMC) was done using the fundamental mode RR Lyrae stars, in collaboration with S. Deb and S. Kumar (DU) and S. M. Kanbur (SUNY, Oswego). The V- and I-band light curves of the RRab stars, obtained by the Optical Gravitational Lensing Experiment (OGLE-III) were utilized in order to comprehend the SMC structure. From the three-dimensional RRab distance distributions, north-east arm and main body of the galaxy are identified. Combining metallicities obtained by using the metallicity-period-Fourier parameter relations, with spatial distribution of these tracers, no radial metallicity gradient in the SMC was detected. Dividing the entire sample into three parts: north-eastern, central and south-western, we found that the central part has a significantly larger line of sight depth as compared to rest of the parts, indicating that the SMC may have a bulge. Results obtained from the I-band data seem to be reliable and were further substantiated using the Smolec relation. Distribution of SMC RRab stars was modelled as a triaxial ellipsoid. Errors in structural parameters of the SMC ellipsoid were obtained from Monte Carlo simulations. We estimated the axes ratios of the galaxy as $1.00 \pm 0.000 : 1.310 \pm 0.029 : 8.269 \pm 0.934$, the inclination of the longest axis with line of sight $= 2.265° \pm 0.784°$ and the position angle of the line of nodes $= 74.307° \pm 0.509°$ from the variance weighted I-band determinations.

Analysis of multi-wavelength variable star light curves

A detailed light curve analysis of fundamental-mode Galactic and Large Magellanic Cloud (LMC) Cepheids was done based on the Fourier decomposition technique in collaboration with A. Bhardwaj (DU) and S. M. Kanbur (SUNY, Oswego), and C. C. Ngeow (Taiwan). We compiled light-curve data for Galactic and LMC Cepheids in optical (VI), near-infrared JHK and mid-infrared (3.6 and 4.5 μm) bands from the literature, and determined the variation of their Fourier parameters as a function of period and wavelength. We observed a decrease in Fourier amplitude parameters and an increase in Fourier phase parameters with increasing wavelengths at a given period. We also found a decrease in the skewness and acuteness parameters as a function of wavelength at a fixed period. We applied a binning method to analyse the progression of the mean Fourier parameters with period and wavelength. We found that for periods longer than about 20 days, the values of the Fourier amplitude parameters increase sharply for shorter wavelengths as compared to wavelengths longer than the J band. We observed the variation of the Hertzsprung progression with wavelength. The central period of the Hertzsprung progression was found to increase with wavelength in the case of the Fourier amplitude parameters and decrease with increasing wavelength in the case of phase parameters. We also observed a small variation of the central period of the progression between the Galaxy and LMC, presumably related to metallicity effects. These results will provide useful constraints for stellar pulsation codes that incorporate stellar atmosphere models to produce Cepheid light curves in various bands.

K. Yugindro Singh

Discovery of an ultra-luminous X-ray source candidate, ULX (X-8) in NGC 3384 with Chandra

We study the previously unexplored Chandra observed X-ray point sources of NGC 3384. While most of the point sources in NGC 3384 are hard

X-ray binaries, we report the discovery of a candidate ultra-luminous X-ray source (ULX), X-8 in NGC 3384 during an effective 28.67 ks Chandra observation. ULX, X-8 is found to have its 0.3–10.0 keV luminosity $\sim 1.52{\times}10^{39}$ ergs s^{-1} and a bolometric luminosity $\sim 2.43{\times}10^{39}$ ergs s^{-1}. The ULX is spectrally hard in X-rays, with $\Gamma \sim 1.97$ when fitted with an absorbed power-law. The spectral property of this object, when fitted with an absorbed disk black body, appears to be consistent with nearly a $30M_{\odot}$ black hole accreting at ~ 0.58 times its Eddington luminosity. The light curve of this ULX source, X-8 has shown no signature of short-term variability in kilo-seconds time scales in the present available Chandra observation. This work has been done in collaboration with A. Senorita Devi.

K. Sriram

Photometry and Hα studies of a low-mass-ratio overcontact binary ASAS J082243+1927.0

A high precision CCD photometric and Hα line studies are presented for a contact binary ASAS J082243+1927.0. The light curve exhibits annular eclipse at secondary minima along with O Connell effect at phase 0.25. The light has been modelled using Wilson Devinney code and the best fit solution provides the mass ratio q = 0.097 and fill-out factor f = 82.5% . These parameters indicate that the system is a deep low mass ratio overcontact binary (DMLROB) system, and is one of the few low mass ratio systems found among this class of binaries. The Hα line equivalent width varied at different phases which is often an observed feature in contact binaries. We find that the line is filled-up at secondary minima, which indicates high activity of the primary component. From a small sample of contact binaries, we find a correlation between the orbital period and Hα line equivalent width of the primary component. Based on sample of forty three deep low mass ratio overcontact binaries, a mass ratio cut-off is observed at $q_{critical} = 0.085$ in mass-ratio period plane. It is observed that below $q_{critical} = 0.085$, period decreases with an increase in q and above it, period increases as the mass ratio increases. Interestingly, the observed mass ratio cut-off value lies close to the critical mass ratio range as predicted in the literature. The observational evidence of the cut-off mass ratio and its variation with orbital period is discussed in terms of mass transfer and angular momentum loss. Based on the photometeric solution, we suggest that the contact binary, ASAS J082243+1927.0 is at the verge of merger, eventually forming a fast rotating star, which seems to be the fate of deep low mass ratio overcontact binaries. This work has been done in collaboration with S.P. Devarapalli, and V.R. Pasagada.

Parijat Thakur

Investigating close-in extra-solar planets through photometric follow-up of their transits

Parijat Thakur and his collaborator (Ing-Guey Jiang) have been investigating close-in extra-solar planets through photometric follow-up of their transits. They have already examined the transit timing variation TTV in the TrES-3 extra-solar planetary system, since it could imply the existence of addition unseen planet. Since the first discovery of a transiting extra-solar planet around HD 209458, 676 transiting extra-solar planetary systems have been confirmed till now and their number is steadily increasing. In the past few years, some ground-based photometric observations have claimed TTVs detections, but none of them is confirmed so far. In this regard, it is suggested by several workers that further high-precision and high-cadence photometric follow-up observations of transiting extra-solar planets will allow 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. In addition to this, the photometric follow-up of transiting extra-solar planetary systems lead to examine the TTVs with greater accuracies, which would confirm the presence or absence of the additional planets in the extra-solar planetary systems. Keeping all these issues in their mind, they still continue to examine close-in extra-solar planets through photometric follow-up of their transits, In order to pursue this work, we plan to carry out further high-precision and high-cadence photometric follow-up of the close-in extra-solar planetary systems during their transits using the observational facilities available in India, as well as in abroad.

Dynamics in the nuclear regions of barred galaxies

Using the smoothed particle hydrodynamics (SPH) simulations, Parijat Thakur and his collaborators (Ing-Guey Jiang, and H.B. Ann) have been working to understand the dynamics of gaseous disk in nuclear regions of barred galaxies, where peculiar nuclear features such as nuclear spirals, nuclear rings, and nuclear bars have been reported from the HST/NICMOS data. Recently, they understand that the model with strong bar shows the formation of nuclear spiral, whose innermost parts reach close to the galactic centre to provide enough fuel for the AGN. However, the innermost parts of nuclear spiral formed in the model with weak bar cannot reach close to the galactic centre to fuel the AGN. In addition, we are interested in examining the effect of the bar strength on the morphology of nuclear spirals, since the visible and near-infrared Hubble Space Telescope (HST) images of active galaxies show that loosely wound nuclear spirals are most frequently observed in barred galaxies, whereas tightly wound nuclear spirals are more common in weak barred/unbarred galaxies. As the pattern speed of bar is important parameter, they would like to examine its effect on the formation of the above said peculiar nuclear features, as well as on the gas inflow in the central kiloparsec regions of barred galaxies.

Udayashankar Paniveni

Supergranulation, a convective phenomenon

Observation of the solar photosphere through high resolution instruments long indicate that the surface of the Sun is not a tranquil, featureless surface but is beset with a granular appearance. These cellular velocity patterns are a visible manifestation of sub-photospheric convection currents which contribute substantially to the outward transport of energy from the deeper layers, thus maintaining the energy balance of the Sun as a whole. Convection is the chief mode of transport in the outer layers of all cool stars such as the Sun (Noyes, 1982). Convection zone of thickness 30% of the solar radius lies in the sub-photospheric layers of the Sun. Here, the opacity is so large that heat flux transport is mainly by convection rather than by photon diffusion. Convection is revealed on four scales. On the scale of 1,000 km, it is granulation and on the scale of 8 - 10 arcsec, it is meso-granulation. The next hierarchial scale of convection, supergranules are in the range of 30 - 40 arcsec. The largest reported manifestation of convection in the Sun are Giant Cells or Giant Granules, on a typical length scale of about 10^8 m.

Supergranules are caused by the turbulence that extends deep into the convection zone. They have a typical lifetime of about 20 hr with spicules marking their boundaries. Gas rises in the centre of the supergranules and then spreads out towards the boundary and descends. Broadly speaking, supergranules are characterized by the three parameters namely, the length L, the lifetime T and the horizontal flow velocity v_h. The inter-relationships amongst these parameters can shed light on the underlying convective processes and are in agreement with the Kolmogorov theory of turbulence as applied to large scale solar convection.

A. A. Usmani

A relativistic mean field study of multi-strange system

We study the binding energies, radii, single-particle energies, spin-orbit potential and density profile for multi-strange hypernuclei in the range of light mass to superheavy mass region within the relativistic mean field (RMF) theory. The stability of multi-strange hypernuclei as a function of introduced hyperons is investigated. The neutron, lambda and sigma mean potentials are presented for light to superheavy hypernuclei. The inclusion of hyperons affects the nucleon, lambda and sigma spin-orbit potentials significantly. The bubble structure of nuclei and corresponding hypernuclei is studied. Nucleon and lambda halo structures are also investigated. A large class of bound multi-strange systems formed from the combination of nucleons and hyperons $(n, p, \Lambda \sum +andn, p, \Lambda \sum -)$ is suggested in the region of superheavy hypernuclei which might be stable against the strong decay. These multi-strange systems might be produced in heavy-ion reactions.

Fully correlated variational Monte Carlo study of ${}^4_\Lambda H$ *and* ${}^4_\Lambda H^*$ *hypernuclei*

Variational Monte Carlo study of ${}^4_\Lambda$H (0^+) and ${}^4_\Lambda$H* (1^+) hypernuclear states using a realistic Hamiltonian and a fully correlated wavefunction including ΛN space-exchange correlation (SEC) is presented. For the strange sector of the Hamiltonian, phenomenological charge symmetric ΛN and ΛNN potentials are used along with Argonne NN(AV18) and Urbana NNN(UIX) potentials for the non-strange sector. Complete energy breakdown, separation energy, polarization of the nuclear core, nucleon radii ($\langle r_p^2 \rangle^{1/2}$ and $\langle r_n^2 \rangle^{1/2}$) and nucleon and Λ density profiles are calculated for the $^4_\Lambda$H hypernuclear state. The 0^+-1^+ energy splitting and complete energy breakdown for 1^+ excited state are also calculated. For the exact assessment of charge symmetry breaking energy, Coulomb energies for the rearranged distributions of protons in $^4_\Lambda$He hypernucleus are calculated. Best set of variational parameters of optimized wavefunctions, both with and without SEC, are found. Dependence of results on various sets of ΛN potential strengths is investigated. Nucleons are pushed towards periphery as well as towards centre by the hyperon which stays in the interior region most of the time. SEC effects are found to be significant. Nuclear core is found to be compact having more polarization energy with SEC in the wavefunction.

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(b) Proceedings

1 **Suresh Chandra** (2014) *Strengths of rotational lines from* H_2CS *molecule and their application,* Exploring Basic and Applied Sciences for Next Generation Frontiers, Lovely Professional University, Phagwara (Punjab) 240.

2 M. Nguyen, **Suchetana Chatterjee**, A. Myers, et al. (2014) *Breaking degeneracies between quasar halo occupation distribution models: Extending direct measurements to redshift 0.6*, Bull. Amer. Phys. Soc., **35**, L1 00058.

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7 **Broja Gopal Dutta**, Tomaso Belloni, and Sara Motta (2014) *Lag variability associated with quasi-periodic oscillations in GX 339-4 during out-bursts, 40th COSPAR Scientific Assembly, Moscow, Russia.*

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9 Sayan Kar, Anirvan Dasgupta, Suman Ghosh, and **Hemwati Nandan** (2014) *Confinement and focusing of geodesics in warped spacetimes,* ICGC - 2011, J. Phys. Conf. Ser., **484**, 012019 [arXiv: 1742.6596].

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15 **Ranjan Sharma** (2014)*, Spacetime inhomogeneity and gravitational collapse,* ICGC - 2011, J. Phys. Conf. Ser., **484**, 012023.

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(c) Books

1 **Suresh Chandra**, Mohit K. Sharma, and Monika Sharma (2014) *Fundamentals of Mechanics*, Cambridge University Press India Pvt. Ltd., New Delhi. (ISBN: 978-93-82993-40-7).

2 **Asis Kumar Chattopadhyay,** and **Tanuka Chattopadhyay** (2014) *Statistical Methods for Astronomical Data Analysis*, Springer Series in Astrostatistics, New York.

(d) Supervision of M. Phil. Thesis:

1 **Naseer Iqbal** (2014) Title: Understanding high energy gamma rays from AGNs, University of Kashmir, Srinagar. Student: Zahir Ahmad Shah

2 **Naseer Iqbal** (2015) Title: Gravitational waves and their recent status, University of Kashmir, Srinagar. Student: Showkat Ahmad Monga

(e) Supervision of Ph.D. Thesis:

1 **Pradip Mukherjee** (2015) Title: Investigations in higher dimensional, field theories (Jointly with Rabin Banerjee), Calcutta University [arXiv: 1502.05536].
Student: Biswajit Paul

2 **Farook Rahaman** (2014) Title: On relativistic models of singularity free compact stars, Jadavpur University.
Student: Indrani Karar

3 **Farook Rahaman** (2015) Title: On some mathematical perspective of wormholes and black holes, Jadavpur University.
Student: Ayan Banerjee

4 **Shantanu Rastogi** (2014) Title: Study of aromatic molecules of astrophysical and environmental importance, D.D.U. Gorakhpur University.
Student: Prabhunath Prasad

5 **Shantanu Rastogi** (2015) Title: Correlation study of late type stars and polyaromatic molecules, D.D.U. Gorakhpur University.
Student: Anju Maurya

Awards and Distinctions

1 **Asis Kumar Chattopadhyay**, selected President of the Operational Research Society of India, for the period 2015 - 17.

2 **Suchetana Chatterjee**, University Grants Commission Start-up Grant for the project: *Investigating the halo occupation distribution properties of Active Galactic Nuclei.*

3 **Sunandan Gangopadhyay,** DST Young Scientist Start up Research Grant for 3 years.

4 **Sushant Ghosh (**Jointly with **Sanjay Jhingan**, M. Sami, and **Anjan A. Sen)** (2015) The Visitor's Award for Research by the President of India, Presented to the Cosmology and Astrophysics Research Group, Centre for Theoretical Physics, Jamia Millia Islamia for path breaking research carried out in the field of Astrophysics and Cosmology.

5 **Dibyendu Nandi** (2014) NASA Heliophysics Grand Challenge Grant Award as Foreign Co-Principal Investigator.

6 **P. N. Pandita,** The Raja Ramanna Fellowship by the Department of Atomic Energy, Government of India.

IUCAA SPONSORED MEETINGS AND EVENTS AT VARIOUS UNIVERSITIES IN INDIA

CCSU ASTRONOMY AND ASTROPHYSICS SUMMER SCHOOL

Cotton College State University, Guwahati with support from IUCAA and "Friends of Cotton" organised a summer school on Astronomy and Astrophysics for undergraduate students at Cotton College State University during June 15 - July 5, 2014.

[For details see Khagol, issue No. 99, July 2014]

INTRODUCTORY WORKSHOP ON RELATIVISTIC ASTROPHYSICS

Introductory Workshop on Relativistic Astrophysics, was organised during August 21 - 23, 2014 at the Department of Physics, Gauhati University.

[For details see Khagol, issue No. 100, October 2014]

INTRODUCTORY WORKSHOP ON RECENT TRENDS IN ASTROPHYSICS AND COSMOLOGY

Introductory Workshop on Recent Trends in Astrophysics and Cosmology, supported by IUCAA was conducted at Manipal Centre of Natural Sciences, Manipal University, during September 4-6, 2014.

[For details see Khagol, issue No. 100, October 2014]

INTERNATIONAL CONFERANCE ON INTERSTELLAR DUST MOLECULES AND CHEMISTRY (IDMC-2014)

IUCAA and Tezpur University jointly organised an International Conference on Interstellar Dust, Molecules and Chemistry (IDMC-2014) at Tezpur during December 15-18, 2014.

[For details see Khagol, issue No. 101, January, 2015]

WORKSHOP ON COSMOLOGY

IUCAA Resource Centre, Kochi in collaboration with S. H. College, Thevara, Kochi organised a Workshop on Cosmology, at S. H. College, during September 10-13, 2014.

[For details see Khagol, issue No. 101, January, 2015]

WORKSHOP ON OBSERVATIONAL ASPECTS OF ASTROPHYSICS AND COSMOLOGY

Workshop on Observational Aspects of Astrophysics and Cosmology was conducted at Department of Physics, Visva-Bharati, Santiniketan, West Bengal, during November 3-4, 2014.

[For details see Khagol, issue No. 101, January, 2015]

WORKSHOP ON CURRENT TRENDS IN NEAR INFRARED ASTRONOMY IN INDIA

Workshop on Current Trends in Near Infrared Astronomy in India was jointly organised by IUCAA, TIFR, and IIA at TIFR Balloon Facility, Hyderabad, during November 25-27, 2014.

[For details see Khagol, issue No. 101, January, 2015]

WORKSHOP ON SOLAR ASTROPHYSICS

IUCAA funded Workshop on Solar Astrophysics was organised at the Regional Science Centre and Planetarium, in Collaboration with Providence Women's College, Kozhikode, during January 19-20, 2015.

[For details see Khagol, issue No. 102, April, 2015]

WORKSHOP ON STATISTICAL APPLICATIONS TO COSMOLOGY AND ASTROPHYSICS

Workshop on Statistical Applications to Cosmology and Astrophysics, was held at Indian Statistical Institute, Kolkata, during February 10-13, 2015.

[For details see Khagol, issue No. 102, April, 2015]

WORKSHOP ON INTRODUCTORY ASTRONOMY AND ASTROPHYSICS

IUCAA sponsored Workshop on Introductory Astronomy and Astrophysics (WIAA-2015) was organised at Department of Physics, Jagannath Barooah College, Jorhat, Assam, during March 13-14, 2015.

[For details see Khagol, issue No. 102, April, 2015]

WORKSHOP ON COSMOLOGY WITH LARGE SCALE STRUCTURES

Workshop On Cosmology With Large Scale Structures, was held at the Centre for Theoretical Physics, Jamia Millia Islamia, New Delhi, during January 5-9, 2015.

[For details see Khagol, issue No. 102, April, 2015]

IUCAA RESOURCE CENTRES (IRCs)

DEPARTMENT OF PHYSICS
COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY, KOCHI

Coordinator : V. C. Kuriakose
Joint Coordinator : Ramesh Babu T.

Data Centre

The Data Centre is being now used by M.Sc. and M. Phil. students for doing projects and research students for their research. Undergraduate and postgraduate students from neighbouring colleges and institutes have carried out their summer projects using the facilities available at the Data Centre.

Research

The thrust areas of research are: Physics of Black Holes, Extended Theories of Gravity, Bose-Einstein Condensation and Quantum Optics. Nine research students are now doing research in these areas.

Workshops and Meetings

1.Workshop on Cosmology

IRC, Kochi in collaboration with S.H. College, Thevara, Kochi organized a 'Workshop on Cosmology' during September 10-13, 2014 at the Department of Physics of S.H. College. This workshop was meant for postgraduate students in Physics in Kerala, and there were about 50 participants. The resource persons of the workshop were: Sanjit Mitra (IUCAA), Anand Narayanan (IIST), K. Indulekha (M G. University), Ninan Sajeeth Philip (St. Thomas College, Kozhencheri), Minu Joy (Alphonsa College, Pala) and V. C. Kuriakose (CUSAT). In addition to the lectures on conventional topics like: Tensor Analysis, General Theory of Relativity and Cosmology, there were lectures on specialized topics like CMBR, Observational Cosmology and Computational Cosmology. Two sessions each were set apart for tutorials and hands-on training. These sessions were handled by Senior Research Scholars: Jishnu Suresh and R. Tharanath (CUSAT), Sheelu Abraham (St.Thomas College, Kozhencheri) and Reju M. Sam (Pondicherry University) and the participants actively involved in these sessions and also during the entire period of the workshop. The resource persons were available for discussions with the students even after their lectures and all the local resource persons were present through out the programme. The workshop was inaugurated by K. Babu Joseph (Former V. C., CUSAT) by giving a talk on 'Perspectives in Cosmology'. Nijo Varghese of S. H. College, Thevara and Joe Jacob of Newman College, Thodupuzha were the local organizers of this workshop.

Participants of the Workshop on Cosmology held at S. H. College, Thevara, Ernakulam.

Sanjit Mitra lecturing to the participants of the Workshop on Cosmology

2. Workshop on Tools and Techniques for Research in Astrophysics at Multi-wavelengths

A workshop on "Tools and Techniques for Research in Astrophysics" was organized by the Department of Physics, University of Calicut, in collaboration with IRC, Kochi during October 15-17, 2014 at the Department of Physics. There were about 80 participants including a few teachers from neighbouring colleges. Ninan Sajeeth Philip (St. Thomas College, Kozhencherrry) inaugurated the workshop. C. D. Ravikumar (UC) introduced the world of practical Astronomy and discussed the details of

Ranjeev Misra talking to the participants of the workshop on Tools and Techniques for Research in Astrophysics at Multi-wavelengths held at University of Calicut.

night sky observations, and also introduced photometry and spectroscopy. This was followed by a discussion on Virtual Observatory (VO) by Ninan Sajeeth Philip, and Sheelu Abraham (Research Scholar, St. Thomas College, Kozhencherrry) led demonstration cum hands-on session on using VO tools and Savithry (Research Scholar, St. Thomas College, Kozhencherrry) discussed X-ray data analysis using XMM observations. On the second day of the workshop, Ranjeev Misra (IUCAA) initiated a discussion on Black Holes in the Universe. A talk on Gamma Ray sources in the Sky was given by Vaidehi Saran Paliya (IIA, Bengaluru) and this was followed by demonstrations using FERMI data. Joe Jacob (Newman College, Thodupuzha) discussed Radio Data Analysis, and Biju K. G. (Research Scholar, Newman College, Thodupuzha) conducted a demonstration session. The last day of the workshop started with talks on Radio Astronomy by Niruj Mohan and Ishwar Chandra, both form NCRA and this was followed by an overview talk on Multi-wavelength Analysis in Astronomy by V. C. Kuriakose (CUSAT).

A. N. Ramaprakash giving seminar

3. Workshop on Astronomy Research: Opportunities and Challenges

This workshop was mainly intended for the researchers in Kerala in areas of Astronomy, Astrophysics and Cosmology, conducted during December 8-12, 2014, and was inaugurated by A. Kembhavi (IUCAA). In this workshop, there were 15 presentations by young researchers and these presentations were sandwiched by talks of A. Kembhavi, Annapurni Subramanyam (IIA), P. P. Divakaran, K. Indulekha (M. G. University, Kottayam), Koshy George (IIA), Anand Narayanan, L. Resmi, and Jagadeep D. (all from IIST, Thiruvananthapuram), B. Sivaraman (PRL, Ahmedabad) and V. C. Kuriakose (CUSAT). P. P. Divakaran and Ranjeev Misra (IUCAA) were present during the entire period of the workshop to give guidelines and to help the young researchers. A. Kembhavi gave a public talk on December 8th evening. There was also a programme for school students named as 'Meet an Astronomer' on December 9th and this was well attended by students from local schools. Ranjeev Misra, P. P. Divakaran, Koshy George and V. C. Kuriakose interacted with them. This workshop was held at Nirmala College, Muvattupuzha and Joe Jacob of Newman College, Thodupuzha and Thomas Varghese of Nirmala College were the local organizers of this programme.

Publications

IRC facilities have been used for the following publications/presentations

1. C. B. Prasobh, and V. C. Kuriakose (2014) *Quasi-normal modes of Lovelock black holes,* Eur. Phys. J. C, **74**, 3136.
2. Nijo Varghese, and V. C. Kuriakose (2014) *Late-time evolution of Dirac field around Schwarzschild-quintessence black hole,* Mod. Phys. Lett. A, **29**, 1450113.

3. R. Tharanath, Jishnu Suresh, Nijo Varghese, and V. C. Kuriakose (2014) *Thermodynamic geometry of Reissener-Nordström-de Sitter black hole and its extremal case,* Gen. Rel. Grav., **46**, 1741.
4. R. Tharanath, Nijo Varghese, and V. C. Kuriakose (2014) *Phase transition, quasi-normal modes and Hawking radiation of Schwarzschild black hole in quintessence field,* Mod. Phys.Lett. A, **29**, 1450057.
5. P. Prasia, and V. C. Kuriakose (2014) *Detection of massive gravitational waves using spherical antenna*, Intl. J. Mod. Phys. D, **23**, 1450037.
6. Jishnu Suresh, R. Tharanath, Nijo Varghese, and V. C. Kuriakose (2014) *Thermodynamics and thermodynamic geometry of Park black hole,* Eur. Phys. J. C, **74**, 2819.
7. C. P. Jisha, Lini Devassy, Alessandro Alberucci, and V. C. Kuriakose (2014) *Influence of the imaginary component of the photonic potential on the properties of solitons in PT-symmetric systems*, Phys. Rev. A, **90**, 043855.
8. Saneesh Sebastian, and V. C. Kuriakose (2015) *Scalar and electromagnetic quasi-normal modes of extended black hole in F(R) gravity,* Mod. Phys. Lett. A, **30**, 1550012.
9. Jishnu Suresh, R. Tharanath, and V. C. Kuriakose (2015) *A unified thermodynamic picture of Horava-Lifshitzblack hole in arbitrary spacetime,* J. High Ene. Phys., **01**, 019.

Seminars/Colloquia

1) IRC Seminar

- **i) M. Vivek :** Beyond the Galaxy' (July 30, 2014)
- **ii) C. Sudha Kartha :** Polymer materials for data storage (March 25, 2015)

2) Celebrating the Centenary Year of General Relativity and International Year of Light February 24, 2015)

IRC, Kochi in collaboration with the Department of Physics and SPIE CUSAT Student Chapter organized a one day seminar to mark the Centenary Year of General Relativity and the International Year of Light. Talks at the seminar were :

A . N. Ramaprakash (IUCAA): Seeing of light

Group photo of the participants of the Workshop on Astronomy Research: Opportunities and Challenges held at Muvattupuzha.

P. P. Divakaran: Mathematical heritage of Kerala

K. Babu Joseph: Light and gravity: What we know and what we don't know

Ramesh Babu T. (CUSAT): Quantum paradoxes.

The programme came to an end with a sky watch session. There were about 50 student participants from neighbouring colleges in addition to the students and research students of the Department.

The Coordinator of IRC has given lectures in other colleges:

1. 'Einstein and Beyond': Motilal Nehru National Institute of Technology, Allahabad (June 12, 2014).
2. 'From Black Clouds to Black Holes': St. Peter's College, Kolencherry (August 13, 2024).
3. 'Observing the Universe', S. H. College, Thevara, Kochi (September 22, 2014).
4. Series of lectures in 'Stellar Physics', Department of Astrophysics, Pondicherry University (November 4-8, 2014).
5. 'Stars: Formation and Evolution', KKTM Govt. College, Pullut, Kodungallur (November 20, 2014).

The Coordinator has also taken part in discussions on scientific topics of current importance in TV channels.

Public Outreach Programme

i) Physics: Awareness programme for school students

Department of Physics, CUSAT, organized a workshop for school students during March 31-April 5, 2014 in collaboration with IRC, Kochi. These students were given training in assembling small telescopes. There were also 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 were given opportunity to visit different research laboratories in the department. There were 40 students for the programme from different schools in Kerala.

ii) Lectures, telescope making and sky watching programmes at colleges

1. S. H. College, Chalakudy (February 25, 2015)
2. Alphonsa College, Pala (February 27, 2015)
3. Govt. Engineering College, Painavu (March 25, 2015)

   IRC, in association with TEQIP (Technical Education Quality Improvement Programme) organized an Astronomy programme at the College on March 25, 2015. Ninan Sajeeth Philip, Joe Jacob, V. C. Kuriakose and Nijo Varghese gave talks introducing the basic aspects of Astronomy to the engineering students and tried to explain the role of Engineers in Astronomy, and the programme came to a close with a sky watch programme.
4. IRC also arranged visits of A.N. Ramaprakash on February 23, 2015 to St. Berchman's College, Changanacherry in the forenoon, and Rajiv Gandhi Institute for Technology, Kottayam in the afternoon. He gave talks and interacted with the students.

The public outreach programme mainly consisted of lectures in general Astronomy, introduction of stellarium software, giving training in making small telescope and sky watching.

The research scholars of the Astronomy and Astrophysics group, R. Tharanath, Saneesh Sebastian and Jishnu Suresh and former student Nijo Varghese rendered valuable services in making the public outreach programme and other activities of the centre a great success.

Coordinator : T. R. Seshadri
Joint Coordinator : H. P. Singh

The IRC, Delhi facilities are being used extensively by several students, postdocs and faculty. It has become a hub for regular discussion of recent papers, pedagogical exposition of specific topics in Astrophysics and related areas, as well as for holding seminars and journal club talks. Its library is also being extensively used not only by reseasrach students but also M.Sc. students.

Seminars held

1. Observational evidence of black holes, Ranjeev Mishra (IUCAA, Pune), June 23, 2014.
2. Constraining dark matter annihilation using the CMB, Mathew Syriac (Stony Brook), September 10, 2014.
3. Magnetic flux concentrations in stratified plasma due to negative effective magnetic pressure instability, Sarah Jabbari (Nordita and Stockholm University), November 24, 2014.
4. Influence of preparation conditions on wetting behaviour of ceramics, V. Madurima (Central University of Tamil Nadu), January 13, 2015.
5. Towards precision cosmology: The halo model and necessary modifications, Irshad Mohammed (Universitat Zurich), January 14, 2015.

Lecture series

21 cm Cosmology : Bidisha Bandhyopadyay

Ph.D. Thesis submitted/awarded using IRC facilites:

1. Cosmological model for accelerated expansion : Shruti Thakur
2. Some aspects of cosmology in higher dimensions : Isha Pahwa
3. Probes of primordial fields in the universe : Pranjal Trivedi

DEPARTMENT OF STATISTICS CALCUTTA UNIVERSITY, KOLKATA

Coordinator : Asis Kumar Chattopadhyay
Joint Coordinator : Narayan Banerjee

Research areas

During this period, the main focus of the research work was on galaxy formation theory through statistical analysis. Some large scale simulation studies have also been carried out. Research scholars and faculty members of different colleges and universities in and around Kolkata have been very much involved in the use of mathematical and statistical software as well as development of computer programmes for the appropriate analysis of astronomical data. They have been also trying to develop new statistical techniques appropriate for the analysis of astronomical data. Some theoretical research work related to theory of relativity and cosmology is also going on.

The following project works have been carried out by the post-graduate students at this centre:

a) Outlier detection in high dimensional astronomical objects by Rajrupa Gupta, Department of Statistics, Presidency University.

Supervised by: Asis Chattopadhyay

b) Detection of proper regression line under unknown cause and effect relationship by Rahul Chowdhury, Department of Statistics, Indian Institute of Technology, Kanpur.

Supervised by: Asis Chattopadhyay

Following are supervised by Tanuka Chattopadhyay from Department of Applied Mathematics, Calcutta University :

c) Study of stellar structure using polytropic model by Ananta Naiya.

d) Study of H-R diagram of real stars using sky map pro-11 by Sourav Mondal.

e) Limit Cycle Model of Star formation by Md Alek Ali.

f) Fragmentation of Molecular clouds under explosive phenomena at Galactic Centre by Riya Sen.

Workshops and meetings

(a) Workshop on Observational Aspects of Astrophysics and Cosmology

A workshop on 'Observational Aspects of Astrophysics and Cosmology' was conducted during November 3 - 4, 2014 at the Department of Physics, Visva-Bharati University, Santiniketan, West Bengal. The workshop was jointly sponsored by IUCAA (through IRC, Kolkata) and Visva-Bharati University. The programme was attended by 60 participants (mostly research scholars) from different parts of the country. The academic staff of the department also participated actively in the workshop.

(b) Regional meeting on Trends and challenges in Astronomy and Astrophysics

The Department of Applied Mathematics, Calcutta University and IUCAA Resource Centre (IRC), Kolkata jointly organized a Regional Meeting on “Trends and challenges in Astronomy and Astrophysics” during the period September 10 - 12, 2015. On the first two days the venue was at the Department of Applied Mathematics, Calcutta University and on the last day it was at the Department of Statistics, Calcutta University.

Publications

1. Tuli De, Tanuka Chattopadhyay, and Asis Kumar Chattopadhyay (2014) *Use of cross correlation function to study formation mechanism of massive elliptical galaxies,* Pub.Astron. Soc. Aus. **31**, 47.
2. Ajit K. Kembhavi, Ashish A. Mahabal, Tejas A. Kale, ..., Asis Kumar Chattopadhyay, et al. (2015) *AstroStat: A VO tool for statistical analysis,* Astron. Comput. (Accepted) , [http://dx.doi.org/10.1016/j.ascom.2015.02.004].
3. Didier Fraix-Burnet, Marc Thuillard, and Asis Kumar Chattopadhyay (2015) *Multi-variate approaches to classification in extragalactic astronomy*, Front. Astron. Space Sci. 2.
4. Pradip Karmakar, Tanuka Chattopadhyay, and Asis Kumar Chattopadhyay (2015) *Study of the nature of dark matter in halos of dwarf galaxies,* Ap. Space Sci., **358**, 46.
5. Tanuka Chattopadhyay, Tuli De, Bharat Warlu, and Asis Kumar Chattopadhyay (2015) *Cosmic history of the integrated galactic stellar Initial Mass Function: A Simulation Study,* Ap. J., **808**, 24.
6. Asis Kumar Chattopadhyay, Saptarshi Mondal, and Atanu Biswas (2015) *Independent component analysis and clustering for pollution data,* Environmental and Ecological Statistics, **22 (1) ,** 33.
7. Sukanta Das, Tanuka Chattopadhyay, and Emmanuel Davoust (2015) *Multi-variate analysis of the globular clusters in M87,* Pub.Astron. Soc. Aus. (in Press) .
8. Ayan Banerjee, Farook Rahaman, and Tanuka Chattopadhyay (2015) *Charged star in (2+1) -dimensional gravity*, Ap. Space Sci., **357**, 29.
9. Tanuka Chattopadhyay, Suma Debsarma, Pradip Karmakar, and Emmanuel Davoust (2015) *Formation of dwarf ellipticals and dwarf irregular galaxies by interaction of giant galaxies under environmental influence,* New Astron., **34**, 151.

Book

Statistical Methods for Astronomical Data Analysis by Asis Kumar Chattopadhyay and Tanuka Chattopadhya, Springer Series in Astrostatistics, 2014.

Seminars and Colloquia

(a) Sanjeev Dhurandhar, IUCAA, Pune on The Fourier transform: Applications to data analysis during February 23 -27, 2015 at the Department of Statistics, Calcutta University.

(b) Marco Banterle, University of Paris 9 – Dauphine, France on Introduction to approximate bayesian computation (ABC) methods on May 18, 2015 at the Department of Statistics, Calcutta University.

Lectures by the Coordinator of IRC

1. Space Marathon, April 10, 2014, Indian Institute of Technology, Kharagpur.
2. Observational Aspects of Astrophysics and Cosmology, November 3 - 4, 2014, Department of Physics, Visva-Bharati University.
3. Census data dissemination, December 19, 2014, Indian Statistical Institute, Kolkata (sponsored by UNFPA).
4. Recent trends in mathematical and computational sciences, January 3 - 4, 2015, T.M. Bhagalpur University.
5. Emerging trends in statistical research: Issues and challenges, February 16 - 17, 2015, Pondicherry University.
6. Environmental statistics, March 2 - 4, 2015, Indian Statistical Institute, Kolkata.
7. 60th ISI World Statistics Congress, July 26 - 31,2015, Rio de Janeiro, Brazil.
8. Fundamentals of biomedical research methods, October 7 - 9, 2015, Regional Occupational Health Centre (Eastern), Salt Lake City, Kolkata.

Research highlights

Samridhi Kulkarni, research student of S. K. Pandey was awarded Ph.D. degree on September 15, 2014. The title of her thesis was "Multiband photometric study of dusty ellipticals and lenticulars". The work mainly comprised of investigation of properties of dust and ionized gas in early type galaxies using their multi-wavelength data. The sample consisted of 40 nearby ($z < 0.02$) early type galaxies. The observations were carried out using 2 m Himalayan Chandra Telescope (HCT), Hanle and 2 m telescope at IUCAA Girawali Observatory (IGO), Pune. The physical association of dust and ionized gas in program galaxies along with their correlation with other forms of interstellar medium were studied and presented in the thesis.

Mayukh Pahari was awarded Ph.D. degree under the supervision of J.S. Yadav and co-supervision of S.K. Pandey on January 27, 2015. The thesis entitled "Understanding accretion and radiation process leading to state transitions in X-ray binaries" comprised of timing and spectral analysis of various BHXBs. Beside this a considerable amount of time was also spent in hard X-ray instrumentations using semiconductor detectors and scintillator detectors. The detail timing and spectral analysis on different variability classes in GRS 1915+105 observed at different luminosities and time scales was performed and their positions on Hardness Intensity Diagram (HID) were determined. By comparing with the HID of other black hole X-ray binaries, an attempt was made to construct a unified picture of the HID of all BHXBs including GRS 1915+105. Study of X-ray outburst evolution in luminous NSXB GX 17+2 and X-ray pulsar 2S 1553-54 was also carried out in this work, which led to identify the characteristic features that can be used to distinguish BHXBs and NSXBs. Detailed comparison of GRS 1915+105 and IGR J17091-3624 shows that X-ray activities in both sources may be related by mass scaling.

Study of the isophotal shapes of early-type galaxies to very faint levels, reaching ~ 0.1% of the sky brightness was carried out in collaboration with A. K. Kembhavi, Russell Cannon, Ashish Mshabal. The galaxies are from the Large Format Camera (LFC) fields obtained using the Palomar 5 m Hale Telescope, with integrated exposures ranging from 1 to 4 hr in the Sloan Digital Sky Survey in r, i, and z bands. The shapes of isophotes of early-type galaxies are important, as they are correlated with the physical properties of the galaxies, and are influenced by galaxy formation processes. The sample consisted of 132 E and S0 galaxies in one LFC field. The redshifts for 53 of these were obtained using AAOmega on the Anglo-Australian Telescope.

The shapes of early-type galaxies often vary with radius. We derive average values of isophotal shape parameters in four different radial bins along the semi-major axis in each galaxy. We obtain empirical fitting formulae for the probability distribution of the isophotal parameters in each bin and investigate for possible correlations with other global properties of the galaxies. Our main finding is that the isophotal shapes of the inner regions are statistically different from those in the outer regions. This suggests that the outer and inner parts of early-type galaxies have evolved somewhat independently. The results are presented in ApJ by Laxmikant Chaware et al. 2014.

Sheetal Sahu Ph.D. student, under the supervision of S.K. Pandey is working on thesis titled "Multi-wavelength study of a sample of radio loud elliptical galaxies". Optical broad band and narrow band images of sample galaxies were obtained using IGO 2 m telescope, and 2 m HCT at IAO, Hanle. We supplement the multi wavelength coverage of the observation by using X-ray data from Chandra, UV data from GALEX, infrared data from 2MASS, Spitzer and WISE, Very Large Array (VLA), Giant Metrewave Radio Telescope (GMRT) and IRAM for radio data. In order to investigate properties of interstellar medium, we have generated unsharp-masked, colour, residual, quotient, dust extinction, Hα emission, CO intensity, X-ray diffuse emission maps. It is evident that cool gas, CO, dust, warm ionized Hα and hot X-ray gas are spatially associated with each other. We also made use of the HST (WFPC2, ACS, NICMOS2) archival images to investigate the properties at the central < 10 arcsec region of the sample galaxies. We are modelling the surface brightness profiles of the galaxy in different wavelengths by fitting a combination of (Power + Sersic) law and Devaucouleur's law and its comparative study for a better fit. We are also investigating the inner and outer photometric and kinematic properties of the galaxy using surface brightness profiles.

Amit Tamrakar Ph.D. student, under the supervision of S.K. Pandey is working on thesis titled "Multi-wavelength isophotal shape analysis of early type galaxies". Multi-band image analysis of a chosen sample of early type galaxies has been done to look for the dust and other faint features. With the isophotal shape analysis, we will try to find statistical correlations between presence of dust with the higher order Fourier coefficients and ellipse parameters using ELLIPSE task in STSDAS. This analysis will improve our understanding regarding the roll of dust and the formation of early-type galaxies.

Mahendra Verma Ph.D. student, under the supervision of S.K. Pandey and Sudhanshu Barwey is working on "Central region of lenticular galaxies". The aim of the proposed work is to carry out detailed analysis of central (nuclear) regions of S0 galaxies observed with Hubble Space Telescope (HST). We plan to use archival multi-band data obtained using various instruments on board HST for a sample of S0 galaxies taken from RC3 catalogue, which contains nearly 3476 S0 galaxies. For our sample those galaxies are selected which come under our volume decide criteria. We downloaded few sample of galaxies from HST

archive, doing surface photometry using IRAF to investigate dust at nuclear region.

Kalyani Bagri a new research student has joined and is working on BHXBs under the supervision of S.K. Pandey and J.S. Yadav.

D. K. Chakraborty and his research group continued their work on intrinsic shape of elliptical galaxies and triaxial mass models.

Study of type Ia supernovae (SNe) bas been carried out by N.K. Chakradhari, S.K. Pandey, in collaboration with G.C. Anupama and D.K. Sahu, IIA, Bengaluru. Photometric and spectroscopic optical observations were carried out using 2 m Himalayan Chandra Telescope. Along with optical data, the UV data from Swift satellite were also analyzed. The work on a peculiar type Ia supernova SN 2012dn, which is a low mass clone of super-Chandrasekhar mass type Ia SNe has been presented in MNRAS. N.K. Chakradhari is also working on study of variability in chemically peculiar stars in collaboration with Santosh Joshi, ARIES Nainital. The pulsational variability in these objects is very important because of their use in asteroseismic study. Hence, to search for pulsational variability in these stars, Nainital-Cape Survey has been initiated, which is one of the longest running surveys working in this field.

School of Studies in Physics and Astrophysics, Pt. R.S. University, Raipur has signed on MoU with ARIRS, Nainital to strengthen the research activities. Chlueshar Sahu, Dharmraj Sahu, and Rishi Raj Saras all are M.Sc. IV semester students have carried out their project work at ARIES, Nainital.

Interaction with the visiting scientists

Following scientists visited the IRC and interacted with the students: N. Dadhich (IUCAA, Pune), R.V. Gavai (TIFR, Mumbai), P.C. Agrawal (TIFR, Mumbai), Srikanth Sastry (JNCASR, Bangalore), Asha Kembhavi (Novozymes, Pune), P. Vivekananda Rao (Osmania University, Hyderabad), H. M. Antia (TIFR, Mumbai), D.K. Srivastav (Director, VECC, Kolkata), Gulab Dewangan (IUCAA, Pune), J.S. Yadav (TIFR, Mumbai), J.V. Narlikar, Mangla J. Narlikar (IUCAA, Pune), Ajit Kembhavi (Director, IUCAA, Pune), Rajat K. Bhaduri (Canada), and Dr. Parijat Thakur (GGU, Bilaspur).

Seminars and popular lectures by visiting scientists

1. Dark Energy, Dark Matter and Bose-Einstein Condonsate by Rajat K. Bhaduri, Canada, February 16, 2015
2. 100 years of Einstein Theory of Gravitation, by Ajit Kembhav, IUCAA, Pune, February 13, 2015.
3. Problems in Astronomy and Mathematics, by J.V. Narlikar, and Mangla J. Narlikar, IUCAA, Pune, February 06, 2015.
4. X-ray Variability of Active Galactic Nuclei, by Gulab Chand Dewangan, IUCAA, Pune, January 28, 2015.
5. LAXPC/ASTROSAT: Instrument development and study of BHXBs, by J.S. Yadav, TIFR, Mumbai, January 28, 2015.
6. Probing the Solar Interior, by H.M. Antia, TIFR, Mumbai, December 27, 2014
7. Giant Telescopes for Astronomy, by Ajit Kembhav, IUCAA, Pune, August 09, 2014.
8. A Big Bang Machine, by R.V. Gavai, TIFR, Mumbai, August 07, 2014.
9. Birth and Death of Stars, Our Sun and its Ultimate Fate, by P.C. Agrawal, TIFR, Mumbai, August 07, 2014.
10. From Newton to Einstein and Beyond, by Naresh Dadhich, IUCAA, Pune, August 07, 2014.

Publications/Poster

1. Laxmikant Chaware, Russell Cannon, Ajit K. Kembhavi, Ashish Mahabal, and S.K. Pandey (2014) *Isophotal shapes of early-type galaxies to very faint levels,* Ap. J., **787**, 102.
2. Samridhi Kulkarni, D.K. Sahu, Laxmikant Chaware, N.K. Chakradhari, and S.K. Pandey (2014) *Study of dust and ionized gas in early-type galaxies*, New Astron., **30**, 51.
3. Sheeta Kumar Sahu, Laxmikant Chaware, and S.K. Pandey (2014) *Multi-phase ISM in radio loud earlytype galaxies,* COSP, **40**, 2843.
4. Sheetal Kumar Sahu, Laxmikant Chaware, S.K. Pandey, Samridhi Kulkarni, and N.K. Chakradhari (2014) *Multi-wavelength study of radio loud early-type galaxies from the B2 sample,* IAUS, **304**, 353.
5. N.K. Chakradhari, D.K. Sahu, S. Srivastav, and G.C. Anupama (2014) *Supernova SN 2012dn: A spectroscopic clone of SN 2006gz,* MNRAS, **443**, 1663.
6. D.K. Sahu, G.C. Anupama, and N.K.Chakradhari (2014) *Optical studies of Type IIb SN 2011dh,* IAUS, **296**, 338.

Public Outreach Programmes

- Planetarium show, sky watching programme and telescope demonstrations were organized at various places for school/ college students, teachers and public.
- Various activities were done during the INSPIRE summer and winter camps.
- Popular Lectures by S. K. Pandey include:

  "A fresh view of the Universe: Tracing our cosmic connection", Rungta College, Bhilai, August 4, 2014.

  "An astronomer's view of the Universe", The Golden Jubilee inaugural function, Govt. P.G. College, Bhatapara, September 10, 2014.

  "Cosmic light: Universe of images", Govt. Digvijay College, Rajnandgaon, February 24, 2015.

  "The grand design of our Universe", Physics Department, Sambalpur University, March 11, 2015.

  "Cosmic archaeology and the scientific temper", The National Seminar on Science Sensitization among Commons, GGD Central University, Bilaspur, March 28, 2015.

An interview on AIR-Vigyan Lok on "Dark matter and dark energy in the Universe", June 2, 2014.

- N.K. Chakradhari delivered a lecture on Astronomy and Astrophysics: Opportunities and Challenges, Govt. College, Balod, January 15, 2015

DEPARTMENT OF PHYSICS
NORTH BENGAL UNIVERSITY, SILIGURI

Coordinator : Dr. B. C. Paul

Research area

Cosmology, Compact Objects, Data Analysis of X-Ray Sources and Pulsars, and Non-linear Dynamics.

Use of data centre : M. Sc. Students have used the computers for their project work. Pragati Pradhan is working in X-ray data analysis in the IRC, for her Ph. D. work.

Workshop and meetings

IRC, NBU coordinated in organizing a one day IUCAA sponsored workshop on Mathematical Aspects of General Relativity at the Department of Mathematics, Salesian College, Siliguri on August 22, 2014. Kavita Sarkar of Mathematics Department was the Coordinator. Around 65 participants from various universities and colleges attended the workshop. Stressing on the complementary role of Physics and Metaphysics, in his inaugural speech, George Thadathil raised the question: “Are we simply meant to decimate ourselves like sparks of dust in the vastly unheard, unsung, unobserved story of this expanding and yet disappearing/ involuting universe?” S. C. Das introduced the subject to non-experts in lucid way. In the plenary session, K. K. Nandi presented various interesting aspects of “Gravitational Lensing.” B. C. Paul summarized the recent observations in cosmology and discussed the results in the framework of the big bang theory. A. Bhadra concluded from his analysis that Higgs field (of God’s particles) is inconsistent with General Relativity.

Seminars organized

1. Mysterious Sun : Durgesh Tripathi, IUCAA, Pune, May 30, 2014
2. Bose – Einstein condensation : Ajay Tripathi, Sikkim University
3. Special polynomials in physics : Rajkumar Roychoudhury, Visva-Bharati University, January 30, 2015
4. Research activities at the school of VLSI, IISET : A. Sengupta, IIEST, Shibpur, January 2, 2015

Visitors

Dibyendu Panigrahi, Sree Chaitanya College, Habra; Durgesh Tripathi, IUCAA, Pune; Ajay Tripathi, Sikkim University; Rajkumar Roychoudhury, Visva-Bharati University, Santiniketan; R. Deb, SMIT, Sikkim; Partha Debnath, ABN Seal College, Coochbehar; Ranjan Sharma, P.D. Womens College, Jalpaiguri; Shyam Das, P.D. Womens College, Jalpaiguri; Pragati Pradhan, St. Joseph College, Darjeeling; Pradip Chattopadhyay, Alipurduar College; and P. Thakur, Alipurduar College.

Publications

1. D. P. Datta, and S. Sen (2014) *Excitation of flow instabilities due to non-linear scale invariance*, Phys. Plasma, **21**, 052311 .
2. A. Palit, and D. P. Datta (2014) *Comparative study of renormalized group and homotopy methods in Van der Pol and Rayleigh equations,* Diff. Eqn. Dyn. Sys., (to appear) .
3. Bikash Chandra Paul, and Rumi Deb (2014) *Relativistic solutions of anisotropic compact objects*, Ap. Space Sci., **354**, 421.
4. P. K. Chattopadhyay, Rumi Deb, and Bikash Chandra Paul (2014) *Relativistic charged star solutions in higher* dimensions, Intl. J. Th. Phys., **53**, 1666.
5. Bikash Chandra Paul (2014) *Dark matter and dark energy in the universe*, Bibechana, **11**, 8.
6. P. Pradhan, C. Maitra, B. Paul, N. Islam, and Bikash Chandra Paul (2014) *Variations in the pulsation and spectral characteristics of OAO 1657-415*, MNRAS, doi:10.1093/mnras/stu1034.
7. Shubhrangshu Ghose, A. Saha, and Bikash Chandra Paul (2014) *Holographic dark energy with generalized Chaplygin gas in higher dimensions*, Intl. J. Mod. Phys. D, **23**, 1450015.
8. S. Ghosh, T. Sarkar, and A. Bhadra (2014) *Newtonian analogue of corresponding space-time dynamics of rotating black holes: Implication for black hole accretion,* MNRAS, **445**, 4463.
9. T. Sarkar, S. Ghosh, and A. Bhadra (2014) *Newtonian analogue of Schwarzschild-de Sitter spacetime: Influence on the local kinematics in galaxies*, Phys. Rev. D, **90**, 063008.
10. Bikash Chandra Paul, and A. S. Majumdar (2015) *Emergent universe with interacting fluids and generalized second law of thermodynamics,* Class. Quant. Grav., **32**, 115001.
11. D. Panigrahi, Bikash Chandra Paul, and S. Chatterjee (2015) *Constraining modified Chaplygin gas parameters,* Grav. Cos.*,* **21**, 83.
12. Ujjal Debnath, and Bikash Chandra Paul (2015) *Evolution of primordial black hole in f(T) gravity with modified Chaplygin gas*, Ap. Space Sci., **355**, 147.

BALANCE SHEET

The Bombay Public Trust Act, 1950. Schedule VIII [Vide Rule (1)]

Name of the Trust : INTER-UNIVERSITY CENTRE FOR ASTRONOMY & ASTROPHYSICS

Address: Post Bag-4,Ganeshkhind, Pune-7. **Registration No. :F-5366 (PUNE) dated 27.1.1989.**

BALANCE SHEET AS AT 31ST MARCH 2015

Sr No.	FUNDS & LIABILITIES	Schedule No.	31.03.2015 Rs.
1	Trust Fund / Corpus	6	5,16,61,094
2	Grant-In-Aid from UGC	7	1,51,29,91,794
3	Other Project Grants	8	4,04,25,357
4	Projects and Other Payable (Net)	9	1,46,94,672
5	Current Liabilities	10 & 10A	57,27,834
6	Income and Expenditure a/c	14	(13,02,10,300)
	Total		1,49,52,90,451

Sr No.	ASSETS & PROPERTIES	Schedule No.	31.03.2015 Rs.
1	Fixed Assets (At cost)	11	1,06,60,43,527
2	Investments / Deposits	12	38,73,03,920
3	Project & Other Receivables (net)	13	54,23,412
4	Current Assets -	13	
	a) Cash, Bank balances & Revenue Stamps		70,96,209
	b) Loans and Advances	13A	1,74,49,898
	c) Deposits		23,32,016
	d) Prepaid Expenses		67,16,809
	e) Advance to Suppliers	13B	29,24,660
	Total		1,49,52,90,451

For Inter-University Centre for Astronomy & Astrophysics

As per Report of even date
For A.H.Joshi & Co.
Chartered Accountants
FRN- 112396W

M.S.Sahasrabudhe
Admin. Officer (Accounts)

N. V. Abhyankar
(Sr.Admn.Officer)

S.A.Joshi
(Partner)
Membership No.037772

A.H. Joshi & Co. PUNE. Chartered Accountants

Place : Pune
Date : 27.07.2015

Prof. A.K.Kembhavi
(Director / Trustee)

Chairperson
Governing Board