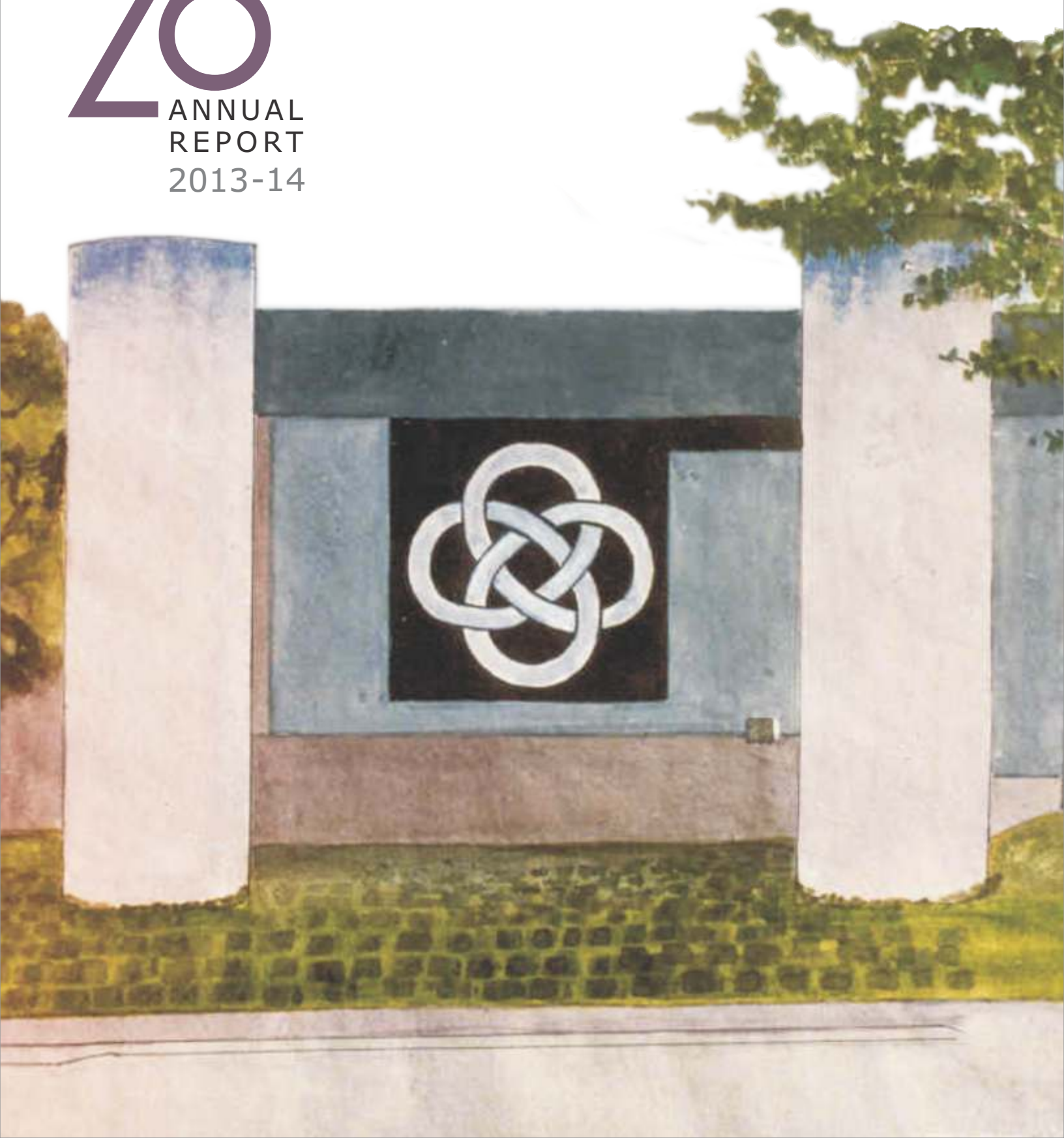
26th ANNUAL REPORT 2013-14

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)



26th ANNUAL REPORT 2013-14

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

EDITOR

AJIT KEMBHAVI

e-mail: akk@iucaa.ernet.in

EDITORIAL ASSISTANT

MANJIRI MAHABAL

e-mail: mam@iucaa.ernet.in

POSTAL ADDRESS : Post Bag 4, Ganeshkhind, Pune 411 007, India
PHONE : (91) (20) 25691414, 25604100 | FAX: (91) (20) 2560 4699
e-mail : publ@iucaa.ernet.in
website : www.iucaa.ernet.in

In this report

THE COUNCIL AND THE GOVERNING BOARD

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Asoke Kumar Sen,
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Ajit K. Kembhavi,
Director,
IUCAA, Pune.

SPECIAL INVITEE

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University Grants Commission,
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The following members have served on the Council for part of the year.

Upamanyu Basu,
Financial Advisor,
University Grants Commission,
New Delhi.

Jitendra N. Goswami,
Director,
Physical Research Laboratory,
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THE GOVERNING BOARD
(As on March 31, 2014)

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Manju Singh (Special Invitee)

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

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Jitendra N. Goswami
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E.P.J. van den Heuvel,
Astronomical Institute, University of Amsterdam, The Netherlands.

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University of Cambridge, UK.

Gerard 't Hooft,
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Donald Lynden-Bell,
Institute of Astronomy, University of Cambridge, UK.

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Govind Swarup,
National Centre for Radio Astrophysics, Pune.

Akhilesh Gupta,
Secretary,
University Grants Commission,
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Department of Physics,
Indian Institute of Science,
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Devang V. Khakhar,
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Renu Batra (Special Invitee),
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University Grants Commission,
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Institute for Gravitation and the Cosmos, USA.

Deepak Dhar,
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Yashwant Gupta,
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Romesh Kaul,
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Ajit K. Kembhavi,
Director,
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P. N. Pandita,
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Astrophysikalisches Institut, Germany.

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T. Ramachandran,
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Dipankar Bhattacharya,
IUCAA, Pune.

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Vice-Chancellor, Tezpur University, Assam.

Sarbari Guha,
St. Xavier's College, Kolkata.

STATUTORY COMMITTEES

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Joydeep Bagchi
Dipankar Bhattacharya
Sukanta Bose
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Swara Ravindranath
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Varun Sahni
Tarun Souradeep
R. Srianand
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Ajit K. Kembhavi (Chairperson)
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Eknath M. Modak (Till September 30, 2013)
T. Padmanabhan
Kandaswamy Subramanian

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Srikumar Banerjee (Chairperson)
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Swarna Kanti Ghosh
Ajit K. Kembhavi
Eknath M. Modak (Till September 30, 2013)
S. K. Ray
Varun Sahni
Jaspal Singh Sandhu

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Ajit K. Kembhavi
(Director)
T. Padmanabhan
(Dean, Core Academic Programmes)
Kandaswamy Subramanian
(Dean, Visitor Academic Programmes)
Joydeep Bagchi
Dipankar Bhattacharya
Sukanta Bose
Gulab Chand Dewangan
Neeraj Gupta (Joined on 15/07/2013)
Ranjan Gupta
Ranjeev Misra
Sanjit Mitra
A.N. Ramaprakash
Swara Ravindranath
Kanak Saha (Joined on 04/12/2013)
Varun Sahni
Tarun Souradeep
R. Srianand
Durgesh Kumar Tripathi

EMERITUS PROFESSORS

Naresh K. Dadhich
Jayant V. Narlikar
Shyam N. Tandon

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Rani S. Bhandare
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Kalpesh S. Chillal
Pravinkumar A. Chordia
Hillol K. Das
Samir A. Dhurde
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Deepa R. Modi
Vijay Mohan
N. Nageswaran
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Swapnil M. Prabhudesai
Sujit P. Punnadi
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Eknath M. Modak (Retired on 30/09/2013)
Niranjan V. Abhyankar
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Vijay P. Barve
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Rahul S. Gaikwad
Sandeep L. Gaikwad
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Prashant S. Jadhav
Ramesh S. Jadhav
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Nilesh D. Kadam
Swati D. Kakade
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Neelima S. Magdum
Manjiri A. Mahabal
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Rajesh D. Pardeshi
Rajesh V. Parmar
Mukund S. Sahasrabudhe
Vyankatesh A. Samak
Senith S. Samuel
Balaji V. Sawant
Deepak R. Shinde
Varsha R. Surve
Deepika M. Susainathan
Shashank S. Tarphe (Joined on 12/03/2014)
Shankar K. Waghela
Kalidas P. Wavhal

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Bibhas Ranjan Majhi
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Arunava Mukherjee
Nidhi Pant
Mandar Patil
Surajit Paul
Jayanti Prasad
Shalima Puthiyaveettil
Angel Ruiz
Prakash Sarkar
Nishant K. Singh
Srividya Subramanian
Shruti Tripathi
Nilkanth Vagshette

RESEARCH SCHOLARS

Anirban Ain
Satadru Bag
Hadi R. Bayegi
Prasanta Bera
Pallavi Bhat
Sumanta Chakraborty
Kabir Chakravarti
Luke Chamandy
Sabyasachi Chattopadhyay
Santanu Das
Rajeshwari Dutta
Bhooshan Gadre
Gaurav Goswami
Charles Jose
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Vikram K. Khaire
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Nagendra Kumar
Sandeep Kumar
Saurabh Kumar
Sibasish Laha
Labani Mallick
Dipanjan Mukherjee
Suvodip Mukherjee
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Hamsa Padmanabhan
Krishnamohan Parattu
Mainpal Rajan
Javed Rana
Pritesh S. Ranadive
Shakti Viraat S. Rathod
Aditya Rotti
Shabbir I. Shaikh
Suprit Singh
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Niranjan D. Bangde

Rupali Bharati
Bhavana Bhojgar
Neelam Bhujbal
V. Chellathurai
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Pratapbhan S. Senger
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Moin Shaikh
Pravin L. Shekade
Monali K. Sinare
Sakya Sinha
Eric Tatulli
Madhukar Togam
Kirti Tonpe
Ajay Vibhute

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Sanjeev V. Dhurandhar
Pushpa Khare
Gopal Krishna

VISITING ASSOCIATES

Farooq Ahmad, Department of Physics, University of Kashmir, Srinagar
Gazi Ameen Ahmed, Department of Physics, Tezpur University
S. K. Saiyad Ali, Department of Physics, Jadavpur University, Kolkata
G. Ambika, Department of Physics, IISER, Pune
Bijan Kumar Bagchi, Department of Applied Mathematics, University of Calcutta, Kolkata
Tanwi Bandyopadhyay, Department of Mathematics, Shri Shikshayatan College, Kolkata
Narayan Banerjee, Department of Physical Sciences, IISER, Kolkata
Shyamal Kumar Banerjee, Department of Mathematics, University of Petroleum and Energy Studies, Dehradun
Prasad Basu, National Institute of Technology, Barfung, Sikkim
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Gour Bhattacharya, Department of Physics, Presidency University, Kolkata
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Ramesh Chandra, Department of Physics, Kumaun University, Nainital
Suresh Chandra, Department of Physics, Lovely Professional University, Phagwara, Punjab
Asis Kumar Chattopadhyay, Department of Statistics, Calcutta University, Kolkata
Surajit Chattopadhyay, Department of Computer Application, Pailan College of Management and Technology, Kolkata
Tanuka Chattopadhyay, Department of Applied Mathematics, Calcutta University, Kolkata
Bhag Chand Chauhan, Department of Physics and Astronomical Sciences, Central University of Himachal Pradesh, Dharamshala
Rabin Kumar Chhetri, Department of Physics, Sikkim Government College, Gangtok
Partha Chowdhury, Department of Physics, University of Calcutta, Kolkata
Mamta Dahiya, Department of Physics and Electronics, S. G. T. B. Khalsa College, Delhi
Himadri Sekhar Das, Department of Physics, Assam University, Silchar
Sudipta Das, Department of Physics, Visva-Bharati University, Santiniketan
Ujjal Debnath, Department of Mathematics, Bengal Engineering and Science University, Howrah
Anoubam Senorita Devi, Department of Physics, Assam University, Silchar
Jishnu Dey, Department of Physics, Presidency University, Kolkata
Mira Dey, Department of Physics, Presidency University, Kolkata
Anjan Dutta, Department of Physics and Astrophysics, University of Delhi
Broja Gopal Dutta, Y. S. Palpara College, Purba - Medinipur
Sunandan Gangopadhyay, Department of Physics, West Bengal State University, Barasat
Sushant G. Ghosh, Centre for Theoretical Physics, Jamia Millia Islamia, Delhi
Sarbari Guha, Department of Physics, St. Xavier's College, Kolkata
Abhinav Gupta, Department of Physics, St. Stephen's College, Delhi
K. P. Harikrishnan, Department of Physics, The Cochin College, Kochi
K. Indulekha, School of Pure and Applied Physics, Mahatma Gandhi University, Kottayam
Naseer Iqbal Bhat, Department of Physics, University of Kashmir, Srinagar
S. N. A. Jaaffrey, Department of Physics, M. L. Sukhadia University, Udaipur
Joe Jacob, Department of Physics, Newman College, Thodupuzha
Deepak Jain, Department of Physics and Electronics, Deen Dayal Upadhyaya College, New Delhi
Sanjay Jhingan, Centre for Theoretical Physics, Jamia Millia Islamia, Delhi
Kanti Jotania, Department of Physics, The M. S. University of Baroda, Vadodara
Minu Joy, Department of Physics, Alphonsa College, Pala
Md. Mehedi Kalam, Department of Physics, Aliah University, Kolkata
Nagendra Kumar, Department of Mathematics, M.M.H. College, Ghaziabad
Suresh Kumar, Department of Applied Mathematics, Delhi Technological University
V.C. Kuriakose, Department of Physics, Cochin University of Science and Technology, Kochi
Badam Singh Kushvah, Department of Applied Mathematics, Indian School of Mines, Dhanbad
Manzoor A. Malik, Department of Physics, University of Kashmir, Srinagar
Soma Mandal, Department of Physics, Taki Government College
Supriyo Mitra, Department of Earth Sciences, IISER, Kolkata
Soumen Mondal, Department of Physics, Ramakrishna Mission Residential College, Kolkata

Pradip Mukherjee, Department of Physics, Barasat Government College, Kolkata
Hemwati Nandan, Department of Physics, Gurukula Kangri University, Haridwar
Kamal Kanti Nandi, Department of Mathematics, North Bengal University, Siliguri
Rajesh Kumble Nayak, Department of Physical Sciences, IISER, Kolkata
Sanjay K. Pandey, Department of Mathematics, L. B. S. (P. G.) College, Gonda
S. K. Pandey, Pandit Ravishankar Shukla University, Raipur
P. N. Pandita, Department of Physics, North Eastern Hill University, Shillong
Amit Pathak, Department of Physics, Tezpur University
Kishor Dnyandeo Patil, Department of Mathematics, B.D. College of Engineering, Sevagram
Madhav K. Patil, School of Physical Sciences, Swami Ramanand Teerth Marathwada University, Nanded
Bikash Chandra Paul, Department of Physics, North Bengal University, Siliguri
Ninan Sajeeth Philip, Department of Physics, St. Thomas College, Kozhencherri
Anirudh Pradhan, Department of Mathematics, Hindu Post-Graduate College, Ghazipur
Farook Rahaman, Department of Mathematics, Jadavpur University, Kolkata
Shantanu Rastogi, Department of Physics, D.D.U. Gorakhpur University
C. D. Ravikumar, Department of Physics, University of Calicut, Kozhikode
Saibal Ray, Department of Physics, Government College of Engineering and Ceramic Technology, Kolkata
Biplab Raychaudhuri, Department of Physics, Visva-Bharati University, Santiniketan
Somak Raychaudhury, Department of Physics, Presidency University, Kolkata
Anirban Saha, Department of Physics, West Bengal State University, Barasat
Rajib Saha, Department of Physics, IISER, Bhopal
Sanjay Kumar Sahay, Department of Computer Science and Information Systems, BITS-Pilani, Goa
Sandeep Sahijpal, Department of Physics, Panjab University, Chandigarh
Pramoda Kumar Samal, Post-Graduate Department of Physics, Utkal University, Bhubaneshwar
Bhim Prasad Sarmah, Department of Mathematical Sciences, Tezpur University
Sanjay Baburao Sarwe, Department of Mathematics, St. Francis De Sales College, Nagpur
Anjan Ananda Sen, Centre for Theoretical Physics, Jamia Millia Islamia, Delhi
Asoke Kumar Sen, Department of Physics, Assam University, Silchar
Somasri Sen, Department of Physics, Jamia Millia Islamia, Delhi
Anand Sengupta, Department of Physics, IIT, Gandhinagar, Ahmedabad
T. R. Seshadri, Department of Physics and Astrophysics, University of Delhi
K. Shanthi, Academic Staff College, University of Mumbai
Ranjan Sharma, Department of Physics, P.D. Women's College, Jalpaiguri
Harinder Pal Singh, Department of Physics and Astrophysics, University of Delhi
Hemam Dinesh Singh, Department of Physical Sciences, Sikkim University, Gangtok
Yugindro K. Singh, Department of Physics, Manipur University, Imphal
Parijat Thakur, Department of Basic Sciences and Humanities, Guru Ghasidas Central University, Bilaspur
Pranjal Trivedi, Department of Physics, Sri Venkateswara College, Delhi
Paniveni Udayashankar, Department of Physics, NIE Institute of Technology, Mysore
Anisul Ain Usmani, Department of Physics, Aligarh Muslim University

From August 2013

Debbijoy Bhattacharya, Manipal Centre for Natural Sciences, Manipur University
Raghavendra Chaubey, Faculty of Science, Banaras Hindu University, Varanasi
Atri Deshamukhya, Department of Physics, Assam University, Silchar
S. Dev, Department of Physics, HNBG Central University, Srinagar, Uttarakhand
Sukanta Dutta, Department of Physics, S. G. T. B. Khalsa College, Delhi
Rupjyoti Gogoi, Department of Physics, Tezpur University
Sk Monowar Hossein, Department of Mathematics, Aliah University, Kolkata
Ngangbam Ibohal, Department of Mathematics, Manipur University, Imphal
L. N. Katkar, Department of Physics, Shivaji University, Kolhapur
Dawood Kothawala, Department of Physics , IIT Madras, Chennai
Rajesh S R, Department of Physics , S. D. College, Alappuzha
L. Sriramkumar, Department of Physics, IIT, Madras, Chennai

VISITING ASSOCIATES

The Twenty-Fourth batch (2013) of visiting associates, who were selected for a tenure of three years, beginning August 1, 2013.

DEBBIJOY BHATTACHARYA

ATRI DESHAMUKHYA

R. CHAUBEY

SUKANTA DUTTA

RUPJYOTI GOGOI

M. HOSSEIN

NG. IBOHAL

LAXMAN KATKAR

S. DEV

L. SRIRAMKUMAR

DAWOOD KOTHAWALA

RAJESH S. R.

Appointment of the following Visiting Associates of the Twenty-first batch were extended for three years: Farooq Ahmad, G. Ambika, Tanwi Bandyopadhyay, Narayan Banerjee, Pavan Chakraborty, Subenoy Chakraborty, B. C. Chauhan, Himadri Sekhar Das, Sushant G. Ghosh, K. P. Harikrishnan, K. Indulekha, Sanjay Jhingan, S. N. A. Jaffrey, Kanti R. Jotania, M. M. Kalam, Nagendra Kumar, B.S. Kushvah, Pran Nath Pandita, Madhav K. Patil, Anirudh Pradhan, Harinder Pal Singh, Biplab Raychaudhuri, Anjan Ananda Sen, Anirban Saha, P. K. Samal, Paniveni Udayshankar and Anisul Ain Usmani.

AWARDS AND RECOGNITIONS

Sumanta Chakraborty

On being awarded the ***Shyama Prasad Mukherjee Fellowship*** for ranking first in CSIR UGC-NET Examination, June 2013.

On being awarded ***Satyendra Nath Bose Memorial Prize*** for ranking first in M.Sc. Part 1 Examination.

Arvind Gupta

On receiving ***IBN Lokmat Prerna Puraskar*** (Science and Technology) by IBN Lokmat, 2014.

Girjesh R. Gupta

On being conferred with ***Justice Oak Best Thesis Award - 2011*** by the Astronomical Society of India.

Jayant Narlikar

On receiving ***Shri Kasba Ganpati Puraskar 2013*** from Shri Kasba Ganpati Sarvajanik Ganeshotsav Mandal Trust, Pune, September 11.

On receiving ***P.D. Patil Maharashtra Bhushan Puraskar*** from Adarniya P.D. Patil Gaurav Pratisthan, Karad, September 17.

On receiving ***Shivajirao Sawant Smurti Puraskar*** from Mrutyunjay Pratisthan, Pune, September 29.

On receiving ***Sivananda Eminent Citizen Award – 2013*** from Sanathana Dharma Charitable Trust, Secunderabad, December 21.

On receiving ***Dr. Yelavarthy Nayudamma Memorial Award – 2013*** from Dr. Y. Nayudamma Memorial Trust, Tenali, Andhra Pradesh.

Hamsa Padmanabhan

On being awarded ***Shri Purushottam Narayan Bhogate Gold Medal, Late Professor Waman Madhav Dabadghav Gold Medal, Late Principal Ranglar Gopalkrishna Laxman-Chandratraya Gold Medal*** for standing first in M.Sc. (Physics) Credit System Examinations April / May 2012 of the University of Pune.

T. Padmanabhan

On being elected to the ***Council of Indian Academy of Sciences (2013-2015).***
On being awarded ***Third Prize in Gravity Essay Contest*** by the Gravity Research Foundation, USA, 2014.

Jayanti Prasad

On receiving the **Start-Up Research Grant** (Young Scientists) by the Science and Engineering Research Board (SERB) of the Department of Science and Technology, Government of India, November 2013.

Tarun Souradeep

On being awarded ***Fellow of International Society on General Relativity and Gravitation*****,** July 2013.

ORGANIZATIONAL STRUCTURE

THE DIRECTOR

Ajit K. Kembhavi

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

DIRECTOR'S REPORT

I am glad to say that during the period of this report, there has been all round progress. IUCAA faculty 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 in IUCAA as well as on other campuses. The year has seen the addition of two faculty members, Neeraj Gupta and Kanak Saha. Gupta specializes in the study of quasars and active galaxies using radio and optical telescopes, while Saha works on galaxy dynamics using numerical simulations. At present, IUCAA has 17 faculty members, apart from the Director, 20 post-doctoral fellows, including one Vaidya – Raychaudhuri fellow and one DST – INSPIRE faculty fellow, and 35 research scholars, including three CSIR – SPM scholars. In addition, there have been several long term senior visiting and emeritus professors. During the year, academic members have published around 120 research papers in high impact national and international journals.

The 11 metre Southern African Large Telescope (SALT), which is 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 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 telescope has had some hardware problems, which were resolved so that observations could be carried out in a limited way. The telescope will soon undergo major refurbishment.

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 half of 2015. The development of the Ultra-Violet Imaging Telescope (UVIT), to be carried by ASTROSAT, has been completed at the Indian Institute of Astrophysics (IIA), Bangalore with Shyam Tandon of IUCAA in the lead. IUCAA has helped with the calibration of the CZT instrument and is preparing to be a point-of-contact for CZT data. IUCAA has helped to develop a sophisticated proposal management system for observations with the satellite and is preparing to set up an ASTROSAT Science Centre for use by all astronomers in the country and beyond.

During the year IUCAA had 105 visiting associates from various universities and colleges. Many associates spend significant periods at IUCAA, accompanied by their research students. They use various facilities at IUCAA and collaborate with the faculty as well as with other visitors to carry out quality research. During the year the visiting associates and their students have published 190 papers in high impact national and international journals. About 25 research students from various universities have used the facilities of IUCAA and carry out a significant part of their Ph. D. research work under the supervision of IUCAA faculty members.

The IUCAA Resource Centres (IRC) at Delhi, Kochi, Kolkata, Raipur, Siliguri, and Udaipur have been working hard to reach the goals for which they were set up. In addition to the IRC, there are IUCAA Nodes for Astronomy and Astrophysics Development (INAAD) 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, at the various

centres and on other university and college campuses.

During the year a number of national and international workshops, schools and conferences have been conducted on the IUCAA campus as well at other places. These include the Gravitational Wave Physics and Astronomy Workshop (GWPAW), MIT – IUCAA Workshop on X-ray Studies of Transient Astronomical Sources, Workshop on Python Programming in Astronomy, and Workshop on Radio Studies of Galaxies and Galaxy Systems, which were all conducted at IUCAA. An Indo – US Joint Centre Meeting and IUCAA –IUSSTF Workshop on Variability of Astronomical Sources was conducted by St. Thomas College, Kozhencherri, Kerala at MACFAST, Thiruvalla.

Professor Jayant Vishnu Narlikar, the founder Director of IUCAA completed 75 years of age on July 19, 2013. To celebrate this milestone, a meeting, 'JVN@75' was organized at IUCAA during July 18 – 19, 2013. The main focus of this meeting was on the areas of Professor Narlikar's scientific work on cosmology and gravitation. There was a very well attended public session to cover his life and times, his influence on the intellectual life of the country, and the setting up of IUCAA by him.

During the year 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 LABS – USA. The project is now in the final stages of approval by the Government of India. IUCAA, with the help of seismologists and other experts, has been engaged with the task of identifying a suitable site for the installation of the detector, and a few sites have been short listed. The Thirty Metre Telescope (TMT) project, of which IUCAA is a lead institute along with Indian Institute of Astrophysics, Bengaluru and ARIES, Nainital has been progressing very well. IUCAA has been actively involved in all aspects of this project. Plans are ready for the construction of a new building on the IUCAA campus which will have offices, lecture halls and a laboratory complex. The new building will house the LIGO – India and TMT projects as well as the ASTROSAT Science Centre.

The National Science Day was celebrated on February 28, 2014 by having an open house for the public of Pune and from the surrounding regions. There were lectures, demonstrations, exhibitions, poster and question-answer sessions throughout the day, and in the night, there was a sky watching programme, which as always led to long queues of people eager to observe the sky through 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.

In 2014 IUCAA has reached the Silver Jubilee of its academic activities. All the exciting work being done at IUCAA over the last 25 years has been made possible through the sincere efforts of its academic, scientific and technical, administration and contractual staff. I say THANK YOU to everyone who has given so much of their time and talents to make IUCAA what it is. I wish to thank the Governing Board members and in particular, the Chairperson, Dr. Srikumar Banerjee, for constant support and encouragement to IUCAA and to me personally. I thank members of the Council, and its President, Professor Ved Prakash, for the fullest support, especially in critical times and situations. Our objectives would not have been met without the help and counsel provided by the University Grants Commission and its officers and staff.

Ajit Kembhavi
Director

ACADEMIC CALENDAR 2013 - 14

Events Outside IUCAA

2013

May 8 - 10
INAAD Radio Astronomy Meeting - II
at St. Thomas College, Kozhencherri
Coordinators: Ninan S. Philip and Joe Jacob

September 2 - 4
Workshop on Astronomy and Astrophysics
at University of Rajasthan, Jaipur
Coordinators: Aruna Bharti, Sandip Bhattacharya and Ranjan Gupta

September 23-26
Workshop on Astronomical Techniques and Science with Virtual Observatories
at University of Kashmir, Srinagar
Coordinators: Ranjeev Misra and Manzor A. Malik

September 26-27
Workshop on Astronomy and Physics for Science Communicators
at JES College, Jalna
Coordinators: M.L. Kurtadikar, Durgesh Tripathi and Samir Dhurde

November 5-15
Autumn School on Cosmology
at BITS-Pilani, Rajasthan
Coordinators: Tarun Souradeep and Debashis Bandyopadhyay

November 19-21
Workshop on Light Scattering Techniques and Application to Astronomy and other areas
at S.N. Bose National Centre for Basic Sciences, Kolkata
Coordinators: S.K. Sharma and Ranjan Gupta

ACADEMIC CALENDAR 2013 - 14

2014

February 10-12
Introductory Workshop on Astronomy and Astrophysics
at Department of Physics, Manipur University, Canchipur, Imphal
Coordinators: K. Yugindro Singh and Ranjan Gupta

IUCAA Events

2013

April 22 – May 31
School Students' Summer Programme

May 6 - June 7
Refresher Course in Astronomy and Astrophysics (For College and University Teachers)

May 6 - June 21
Vacation Students' Programme

July 18 - 19
Jayant@75
Coordinator: Ajit Kembhavi

December 17-20
Gravitational Waves Physics and Astronomy Workshop (GWPAW)
Coordinator: Sukanta Bose

2014

January 13-24
MIT-IUCAA Workshop on X-ray Studies of Transient Astronomical Sources
Coordinator: Dipankar Bhattacharya

January 31 – February 2
Workshop on Transient Astronomy with Small Telescopes
Coordinator: Gulab Dewangan

February 17-21
Workshop on Python Programming in Astronomy
Coordinator: Kaustubh Vaghmare

March 04 -06
Workshop on Radio Studies of Galaxies and Galaxy Systems
Coordinators: R. Srianand and Gopal Krishna

IUCAA Resource Centre Events

2013

August 12-14
Workshop on Astronomy Research : Opportunities and Challenges
at MACFAST, Thiruvalla
Coordinators: Ninan S. Philip and Joe Jacob

December 16-17
Workshop on Analysis of Astronomical Data
jointly organized by IRC, North Bengal University and IRC, Calcutta University.
Coordinators: B. C. Paul and Asis Chattopadhyay

2014

January 10-12
Science and Astronomy Camp
at Birbham Institute of Engineering and Technology, Suri
Coordinator: Asis Chattopadhyay

January 20-24
Workshop on Variability of Astronomical Sources
at St. Thomas College, Kozhencherri
Coordinator: Ninan S. Philip

IUCAA Annual Events

2013

December 29
Foundation Day

2014

February 28
National Science Day

Quantum Theory and Gravity

General relativity in a thermodynamic, holographic language

The emergent gravity paradigm

The uncanny similarity between the laws of black hole dynamics and classical thermodynamics, discovered in the seventies, suggested a possible connection between gravitational dynamics and horizon thermodynamics. This was further strengthened by the work of Davies and Unruh, who showed that black holes are in no way special and that thermodynamic parameters like temperature will be attributed to *any* null surface by observers who perceive the null surface as a horizon due to their state of motion, even in flat spacetime. This allows one to introduce the concept of local Rindler observers around any event in a spacetime just as one introduces freely falling observers around any event. The fact that observers in different states of motion will attribute different thermodynamic features to null surfaces, introduces a new level of observer dependence into the physical theory.

Several further investigations regarding the dynamics of gravity have shown that this connection is far deeper than it has been originally suspected. In particular, we now know that the relation between horizon thermodynamics and gravitational dynamics transcends Einstein's theory of gravity and holds for a much wider class of models like, e.g., Lanczos-Lovelock models. Such investigations by many groups, especially **T. Padmanabhan** and collaborators (reported in previous years) have led to the *emergent gravity paradigm* in which the gravitational field equations have the same status as the equations of elasticity or fluid mechanics. Work done by **Padmanabhan** during the 2013 (highlighted as Editor's choice in *Gen. Rel. Grav* in which it is published) provides significant additional evidence for this paradigm within the context of general relativity. Briefly stated, this work presents dynamics of spacetime in a thermodynamic, holographic language, in contrast to the usual geometric language. **Padmanabhan** has now shown that the gravitational dynamics in a bulk region of space can be connected to a thermodynamic description in the boundary of that region, thereby providing clear physical interpretations of several mathematical features of classical general relativity. In particular:

- The Noether charge contained in a bulk region, associated with the time evolution vector field, has a direct thermodynamic interpretation as the gravitational heat content of the boundary surface.
- This result, in turn, shows that all static spacetimes maintain holographic equipartition. That is, in these spacetimes, the number of degrees of freedom in the boundary is equal to the number of degrees of freedom in the bulk.
- In a general evolving spacetime, the rate of change of gravitational momentum is related to the difference between the number of bulk and boundary degrees of freedom. *It is this departure from the holographic equipartition which drives the time evolution of the spacetime.*
- When the equations of motion hold, the (naturally defined) total energy of the gravity plus matter within a bulk region, will be equal to the boundary heat content.
- After motivating the need for an alternate description of gravity (if we have to solve the cosmological constant problem), **Padmanabhan** provides a thermodynamic variational principle based on null surfaces to achieve this goal. The concept of gravitational heat density of the null surfaces arises naturally from the Noether charge associated with the null congruence. The variational principle, in fact, extremises the total heat content of the matter plus gravity system.

Some of these results are elaborated in the next few subsections.

Natural variables to describe spacetime (thermo)dynamics

In the previous year, **Krishnamohan Parattu, Bibhas Majhi and T. Padmanabhan** have shown that the link between horizon thermodynamics and gravitational dynamics become clearer if we use two $q^{ab} \equiv \sqrt{-g}g^{ab}$ (instead of the metric) and the corresponding

canonical momenta p^c_{ab} (instead of Christoffel symbols). These variables are, of course, not new and have appeared in classical literature, but the work by them provided a fairly comprehensive discussion of these variables and demonstrated how the description of gravity takes a simple and elegant form in terms of these variables. Recent work by **Padmanabhan** has shown that these variables allow the field equations to be written in the form

$$-\nabla_c(\pounds_q p^c_{ab}) = 8\pi \pounds_q \mathscr{F}_{ab}; \qquad \mathscr{F}_{ab} \equiv T_{ab} - \frac{1}{2}g_{ab}T.$$

This exact equation relates the variation of the gravitational momentum density $\pounds_q p^c_{ab}$ (in the form of a Lie derivative along an arbitrary vector field q^a) to the corresponding variation in the Ricci tensor and - through gravitational dynamics - with the variation of the energy momentum tensor.

Previous work by **Parattu, Majhi and Padmanabhan** has established that there is a one-to-one correspondence between the variations of the dynamical variables ($q^{ab}\delta p^c_{ab}$, $p^c_{ab}\delta q^{ab}$) and the variations of the thermodynamic variables ($S\delta T, T\delta S$), when evaluated on the null surfaces for a specific class of metric variations which preserve the null surface geometry. In fact, we will repeatedly encounter the variation $q^{ab}\delta p^c_{ab}$ and it is important to keep in mind the thermodynamic correspondence between this variation and $S\delta T$.

The $T\delta S$ versus $S\delta T$

The fact that two such variations - $S\delta T$ and $T\delta S$ - exist and can be related to each other is not often emphasized and **T. Padmanabhan** has highlighted several feature of this in the context of standard black hole thermodynamics, in which the addition of a mass δM changes the energy of the black hole by the standard relation $\delta M = \delta E = T\delta S$. While this relation is often taken for granted as "natural" without a second thought, it does contain a very peculiar feature: The absence of a $S\delta T$ term makes it appear as though T is kept constant while the process takes place, which, of course, is not true since the change in M changes both T and S of the black hole. In fact, the Schwarzschild black hole (with horizon area A) satisfies the relation (with $L_P^2 = (G\hbar/c^3)$, being the Planck area):

$$E = 2TS = \frac{1}{2}T\left(\frac{A}{L_P^2}\right)$$

with a crucial factor of 2 [and (1/2)] in the two equalities above. The second relation tells us that, if we attribute $N_{\rm sur} = A/L_P^2$ degrees of freedom to the horizon area A, then each degree of freedom carries exactly $(1/2)k_BT$ amount of energy. This, in turn, tells us that if we attribute $N_{\rm bulk} \equiv [E/(1/2)T]$ degrees of freedom with the bulk gravitational energy inside the horizon ("equipartition"), then the black hole is in holographic equipartition with $N_{\rm sur} = N_{\rm bulk}$. It follows that

$$\delta E = 2S\delta T + 2T\delta S,$$

with both the variations contributing to the change in energy. However, there is an additional relation $S \propto M^2 \propto T^{-2}$, which is maintained during the variation that comes to our rescue, allowing us to express δE either in terms of δS or in terms of δT alone:

$$\delta E = T\delta S = -2S\delta T = -\frac{1}{2}\frac{A}{L_P^2}\delta T = -\frac{1}{2}N_{\rm sur}\delta T.$$

While the first equality is so widely discussed, the remaining (equally valid) relations are seldom emphasized in the literature! The equation for E tells us that addition of energy can also be thought of as resulting in an increase in the temperature while the number of surface degrees of freedom is held fixed, with the crucial minus sign indicating the negative specific heat of the gravitating system. While, in reality, both S and T change in the physical processes involving the horizon, they could be described in a complementary fashion, as either $T\delta S$ or as $-(1/2)(A/L_P^2)\delta T$. (The latter is, in fact, similar to the description of, say, heating a mono-atomic ideal gas with $\delta E = (3N/2)\delta T$; we do not change N while heating a fixed amount of gas.) In the general context of null surfaces and other boundaries, we have found that it is the latter interpretation involving δT (which corresponds to δp^a_{bc}) that provides a more natural description. As a result, we continuously encounter this variation in different guises while studying the boundary thermodynamics. Roughly speaking, q^{ab} acts like an extensive variable in thermodynamics, while p^c_{ab} acts like an intensive variable.

A closely related quantity is the total variation $\delta(q^{ab}p^c_{ab})$, which corresponds to $\delta(TS)$. This expression arises when we study the contribution of the boundary term in the Einstein-Hilbert action on a local Rindler horizon, and it occurs without

the factor 2 noted earlier. **Padmanabhan** has discussed the physical significance of this term (and the difference between TS and $2TS$) in his work in earlier years. The TS essentially corresponds to the enthalpy (or heat content) of the gravitational field, which measures the difference between the energy and free energy of a finite temperature system, while $2TS$ measures the equipartition energy obtained by attributing $(1/2)k_BT$ to each of the (A/L_P^2) degrees of freedom in an area A. The basic result in the context of black holes, written in two forms:

$$\begin{aligned} 2(TS) &= 2(M/2) = \frac{1}{2}T(A/L_P^2) \\ & \quad 2(\text{heat content}) \\ & \quad = (\text{equipartition energy}) \end{aligned}$$

will keep appearing in our discussions.

Thermodynamic interpretation of Noether current

T. Padmanabhan provides a simple relationship between the above concepts, Noether currents and the gravitational dynamics. To do this consistently, he has shown how Noether currents can be thought of as arising purely from some, actually rather trivial, mathematical identities in differential geometry, unlike the usual procedure involving action functional and its diffeomorphism invariance. While one can associate a conserved current with *any* vector field in spacetime, the vector field related to the time evolution is special. If we foliate the spacetime in the usual manner with u_a denoting the unit normal to the t = constant surfaces, then the vector field which is closely related to time evolution is $\xi^a \equiv Nu^a$, where N is the lapse function. This vector is related to the flow of proper time normal to the t = constant surfaces and is parallel to the velocity vector u^a of the fundamental observers. **Padmanabhan** has shown that one can obtain quite elegant and physically pleasing results from the Noether current and charge corresponding to the vector ξ^a. To begin with, the total Noether charge (associated with ξ^a) in any bulk region $\mathcal{V}$ bounded by a constant lapse surface $\partial\mathcal{V}$, is equal to the heat content of the boundary surface. Further, twice the Noether charge gives the equipartition energy of the surface:

$$\int_{\mathcal{V}} \sqrt{h}, d^3x \; u_a J^a[\xi] = \int_{\partial\mathcal{V}} d^2x \; Ts;$$

$$2\int_{\mathcal{V}} \sqrt{h}\, d^3x \; u_a J^a[\xi] = \int_{\partial\mathcal{V}} \frac{\sqrt{\sigma}\, d^2x}{L_P^2}\frac{1}{2}(k_BT).$$

The temperature and entropy density of a patch of area are defined using local Rindler observers. This result holds in arbitrary, time evolving, spacetimes and provides a simple and direct interpretation of the Noether charge associated with one of the time development vectors.

The factor 2 on the left hand side of the second equation given above solves what is considered a problem in standard general relativity. We have seen that the Noether charge is *half* of the thermal, equipartition, energy of the surface $(1/2)TA = 2TS$ if we attribute $(1/2)T$ per surface degree of freedom. In the case of the Schwarzschild geometry, say, the thermal, equipartition, energy of the surface is just the total mass $M = 2TS$. *But what the Noether charge measures is the heat content (enthalpy) $E - F = TS$ which is precisely $(M/2)$.* In fact, this is a well-known "problem" when one tries to define total mass of a spacetime (which asymptotically tends to the Schwarzschild limit) using the so called Komar integral. In this context, ξ^a will become the standard timelike Killing vector and the Noether potential will be the Komar potential. The integral one performs with the Killing vector ξ^a is identical to the computation of the Noether charge above and one gets $(M/2)$. In classical relativity, this was considered very puzzling, because in classical general relativity we (at best!) only have a notion of energy but no notion of heat content (TS), free energy $(F = E - TS)$, etc. The thermodynamic perspective, which requires $\hbar$ to define the Davies-Unruh temperature $k_BT = (\hbar/c)(\kappa/2\pi)$ from an acceleration κ tells us that the Noether charge is the heat content (enthalpy) TS and *not* the energy $2TS$, and that the result *must* be $M/2$ for consistency. In short, classical general relativity can only interpret M physically (as energy) while the thermodynamic considerations allow us to *also* interpret $M/2$ physically as the heat content TS. *This is yet another case of thermodynamic considerations throwing light on some puzzling features of classical general relativity.*

We have seen that the Noether charge has a delightfully simple interpretation as the surface

heat content (or half the surface equipartition energy) in the most general context. We did not have to assume static nature, existence of Killing vectors, asymptotic behaviour, etc. As long as the boundary is an $N(t, \mathbf{x}) =$ constant surface in an otherwise general context, the Noether charge for the time development vector, contained in a bulk region of space is equal to the boundary enthalpy. To do this, we have only used results from quantum field theory in curved spacetime and have *not* used the gravitational field equations.

Evolution of spacetime as a quest for holographic equipartition

The above relation also allows one to study the concept of holographic equipartition (introduced by **T. Padmanabhan** in several previous works) in static spacetimes, and more importantly relate the time evolution of the spacetime geometry to the departure from holographic equipartition. He has now shown that the time evolution of the spacetime geometry, *in the most general context*, can be described in a rather elegant manner by the equation:

$$\int_{\mathcal{V}} \frac{d^3x}{8\pi}\sqrt{h}u_a g^{ij}\pounds_\xi p^a_{ij} = \frac{1}{2}k_B T_{\rm avg}(N_{\rm sur} - N_{\rm bulk}),$$

where $T_{\rm avg}$ is the average Davies-Unruh temperature of the boundary of $\mathcal{V}$. On the left hand side, we again see the rate of change of gravitational momentum, which in thermodynamic language is related to the change in the temperature. The above equation shows that this change is driven by the departure from holographic equipartition, and that the time evolution will cease when $N_{\rm sur} = N_{\rm bulk}$. The holographic equipartition law in the form $N_{\rm sur} = N_{\rm bulk}$ for any static spacetime, derived previously, now appears as a special case.(See Figure 1)

This result is conceptually quite significant. A good test of emergent gravity paradigm is that we must be able to rewrite the field equations in a language better adapted to thermodynamic concepts rather than to geometric concepts. This is because of the philosophical shift from "gravity is geometry" to "gravity is the thermodynamic limit of some microscopic spacetime degrees of freedom". This reinterpretation must come fairly naturally from the mathematical formulation if the ideas are correct. The above result demonstrates this feature.

A closely related result pertains to the definition and evaluation of the energy associated with gravity in a bulk region of space. The description of gravity in terms of (q^{ab}, p^c_{ab}) provides a natural way of associating a gravitational four-momentum current with every vector field. One can show that the total amount of gravitational energy contained in a bulk region is then exactly equal to the surface heat content when the equations of motion hold. That is, for any self-gravitating system, which could be time-dependent and dynamically evolving, the total energy contained in a region $\mathcal{R}$ bounded by a constant lapse surface $\partial\mathcal{R}$, is given by:

$$\int_{\mathcal{R}} d^3x\sqrt{h}u_a[P^a(\xi) + NT^a_b u^b] = \int_{\partial\mathcal{R}} d^2x\; Ts.$$

On the left hand side, the first term is the suitably defined gravitational contribution to the energy density, and the second term is the contribution from matter. The validity of the above result is *not* restricted to static spacetimes, which, in turn, implies that this energy and the boundary heat content will evolve in time due to physical processes. One can easily determine the variation of this energy with respect to the time development vector. This is given by:

$$\pounds_\xi H_{\rm grav} = \int_{\partial\mathcal{R}} d^2x\,\sqrt{\sigma}\,N r_a\left(T^{ab}\xi_b + g^{lm}\pounds_\xi p^a_{lm}\right),$$

where r_a is the normal to $\partial\mathcal{R}$. Of the two terms in the integrand, the first one is due to the matter energy flux across the boundary. The second term, representing the gravitational sector, again has the variation of p^a_{lm}, which reinforces the idea that this term can be thought of as the change in the gravitational heat due to the processes at the boundary.

Thermodynamic variational principle for the field equations

There are strong arguments to suggest that the *so called cosmological constant problem is a clear indication that we are ignoring the most significant clue we have about the nature of gravitational dynamics*: Gravity does not couple to changes in the bulk energy density arising from the addition of a constant to the matter

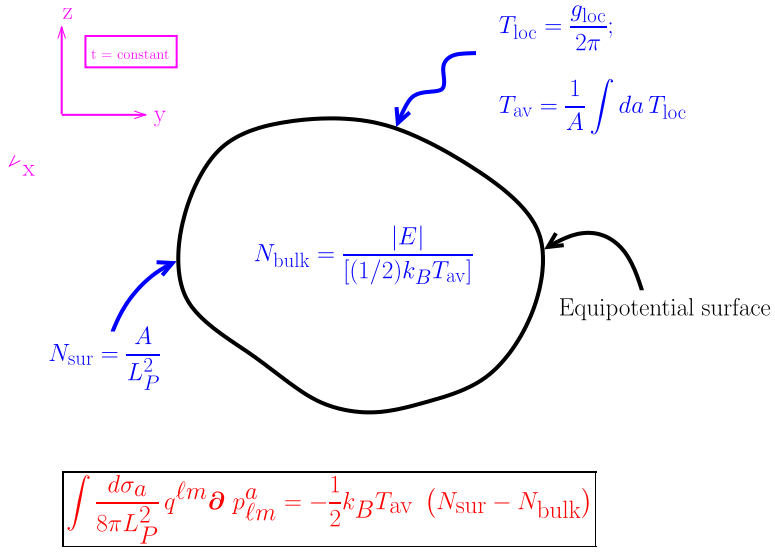

Figure 1: The time evolution of spacetime metric arises due to the deviation from holographic equipartition. At any given time, we consider a region of 3-dimensional space bounded by a 2-dimensional surface marked as 'equipotential surface' on which the lapse function is constant. (This is a natural generalization of the notion of equipotential surface to general relativity.) We assign $N_{sur} = A/L_P^2$ microscopic degrees of freedom with this surface, where A is its area and L_P is the Planck length. Using the notion of local Rindler observers, one can also associate a temperature T_{loc} with any point on the 2-surface, and thus, an average temperature to the surface. If the surface encloses an energy E then one can define the bulk degrees of freedom as the equipartition value $N_{bulk} = |E|/[(1/2)k_B T_{av}]$. It then turns out that the dynamical evolution of metric, given by the left hand side of the boxed equation is caused by $(N_{sur} - N_{bulk})$ and all static spacetime obey holographic equipartition in the form $(N_{sur} = N_{bulk})$. This provides a thermodynamic, holographic description of spacetime evolution.

Lagrangian. **T. Padmanabhan** has argued in several previous papers that one cannot solve the cosmological constant problem in any generally covariant theory in which the metric is varied as a dynamical variable, in an unrestricted manner in a local action principle. A viable alternative is to obtain the field equations of gravity as a consistency condition for the spacetime from a variational principle involving some other dynamical variable. As shown by **Padmanabhan** and Aseem Paranjape several years ago, this is indeed possible (not only for Einstein's gravity but even for all Lanczos-Lovelock theories) by defining a thermodynamic functional on every null surface and demanding that this functional should be extremised simultaneously on all null surfaces.

This formalism can be related to the heat density of the null surfaces and to a Noether charge. In this case, the Noether current is evaluated for the null vector defining the congruence, which is analogous to the time development vector in the case of spacelike surfaces discussed earlier. It turns out that the field equations for gravity can be obtained by extremising the following functional on all null surfaces simultaneously:

$$Q \equiv \int_{\lambda_1}^{\lambda_2} d\lambda \; d^2x \, \sqrt{\sigma} \left[\frac{1}{16\pi} \, g^{ij} \ell_a \pounds_\ell p^a_{ij} + T_{ab} \ell^a \ell^b \right].$$

Here, ℓ^a is the affinely parametrized null vector defining the congruence. The occurrence of $g^{ij} \pounds_\ell p^a_{ij}$, which is related to $S\delta T$ shows that this extremum principle has a purely thermodynamic interpretation. This strengthens the physical interpretation of the variational principle and relates it to the corresponding concepts on spacelike and timelike boundaries.

Spontaneous evolution to classicality in interacting quantum systems

Can a system which exhibits quantum behaviour be steered to classicality by tuning the interaction between its constituent parts only, without any reference to *a* large number of environmental degrees of freedom, which are required for the emergence of classicality by the scheme of quantum decoherence? This question is important because we know at least one system which seems to have become classical without help from an environment: our Universe. **Kinjalk Lochan, Krishnamohan Parattu** and **T. Padmanabhan** have addressed this question by considering a simple model of two interacting harmonic oscillator degrees of freedom, x_1 and x_2, with frequencies ω_1 and ω_2 and a coupling $\lambda x_1 x_2$.

This system can be decomposed into its eigen modes, which will be two uncoupled oscillator degrees of freedom, say X_+ and X_-. If the interaction strength, λ is increased beyond a certain critical value, one of the modes, say X_-, would start obeying an inverted harmonic oscillator potential. It is a known fact that evolution of a Gaussian state under the inverted harmonic oscillator potential would lead to the emergence of classical correlation, with the Wigner function, the quasi-probability distribution in quantum phase space, peaking around the classical trajectory. The behaviour of one of the original modes, say x_2, is examined in this super-critical limit. For a wide class of initial wave functions, it has been proved that the reduced Wigner function for mode x_2, obtained by integrating out the mode x_1, peaks around the classical trajectory in the late time limit, provided the parameters of the Lagrangian are chosen such that mode x_2 is aligned in a direction very near the eigen mode X_- in (X_+, X_-) space. When $\omega_1\omega_2 >> \lambda^2/\omega_1^2$, the mode x_2 is found to satisfy a criterion for classicality. For the same parameters, mode x_1 has been examined and found to remain quantum even in late time limit. On the other hand, both modes remain quantum at all times when the coupling is subcritical.

Thus, they have provided a model where classicality can arise purely due to strong interaction between the constituent parts of a system, without the need for an environment. The toy model that they have considered could have important implications in cosmology (in examining how the observed universe became classical, for example) and in black hole physics.

Evolution of quantum field, particle content and classicality in the three stage universe

The quantum fluctuations generated during the inflationary period become classical after hubble exit and have utmost importance in the universe we perceive today. In the standard approach, one computes the quantum fluctuations of the field at the time when the mode exits the Hubble radius in

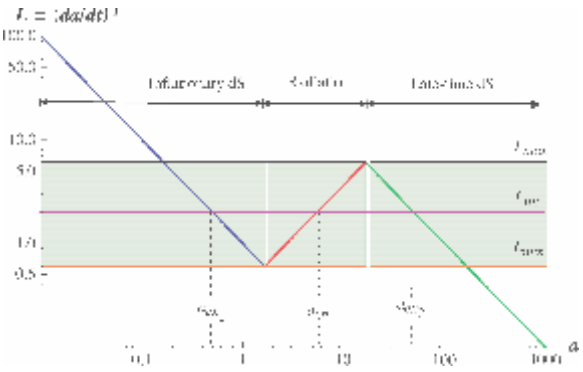

Figure 2: The three stages universe. Evolution of comoving Hubble radius with the scale factor a is shown in the inflationary phase (decreasing), radiation-dominated phase (increasing) and in late-time de Sitter phase (decreasing), where the lines have slopes ± 1 in the logarithmic plot. We have two characteristic length scales, L_{max} and L_{min} forming a band such that any length scale within the band has three transition points where it goes super-Hubble, sub-Hubble and finally super-Hubble again.

the initial de Sitter phase. The Fourier transform of this C-number is then identified with the stochastic fluctuations of a *classical* random field at the time of re-entry of the mode to the Hubble radius. The justification for this procedure is based on two factors: (a) The modes behave classically once they are well outside the Hubble radius. (b) It is assumed that once they become classical they stay classical, and hence, can be described by standard perturbation theory after they re-enter the Hubble radius.

Though this scenario is by now widely accepted (and the results of such a computation agrees well with observations), it must be noted that the quantum to classical transition of the density perturbations is still not completely well understood from a conceptual point of view and has been a challenge for a long time.

To get a handle on this, **Suprit Singh**, **Sujoy K. Modak** and **T. Padmanabhan** have studied the evolution of a quantum scalar field in a toy (*but very close to the real*) universe which has three stages of evolution (see Figure 2), viz., (i) an early (inflationary) de Sitter phase, (ii) radiation dominated phase and (iii) late-time (cosmological constant dominated) de Sitter phase determining the (time-dependent) particle content of the field, set up in the vacuum state initially, for the entire evolution of the universe. The quantum to classical transition is described in terms of a *classicality parameter*, which tracks the particle creation and its effect on phase space correlation of the quantum field giving an intuitively clear, quantitative, measure for the classicality of the fluctuations.

The evolution of field modes as a test field *does* confirm the standard assumptions (a) that modes become classical when they leave the Hubble radius (see Figure 3). What is more is that the degree of classicality can be quantified as the universe evolves. But analysis also shows that, when the mode re-enters the Hubble radius, the degree of classicality does not stay constant but rapidly oscillates. This fact can have important implications for structure formation scenarios, which are based on the factor (b) above, that once the fluctuations are classical, they remain classical.

Alternative gravity theories

Sumanta Chakraborty has discussed the general misconception regarding velocity measurements of a test particle as it approaches black hole by introducing generalized observer set. For a general static spherically symmetric metric, applicable to both Einstein and alternative gravities as well, he has found that velocity of the test particle do not approach that of light at event horizon by considering ingoing observers and test particles. With Soumitra Sengupta, **Chakraborty** has estimated the perihelion precession of planetary orbits and the bending angle of null geodesics for different gravity theories in string-inspired models. They have found that in some cases

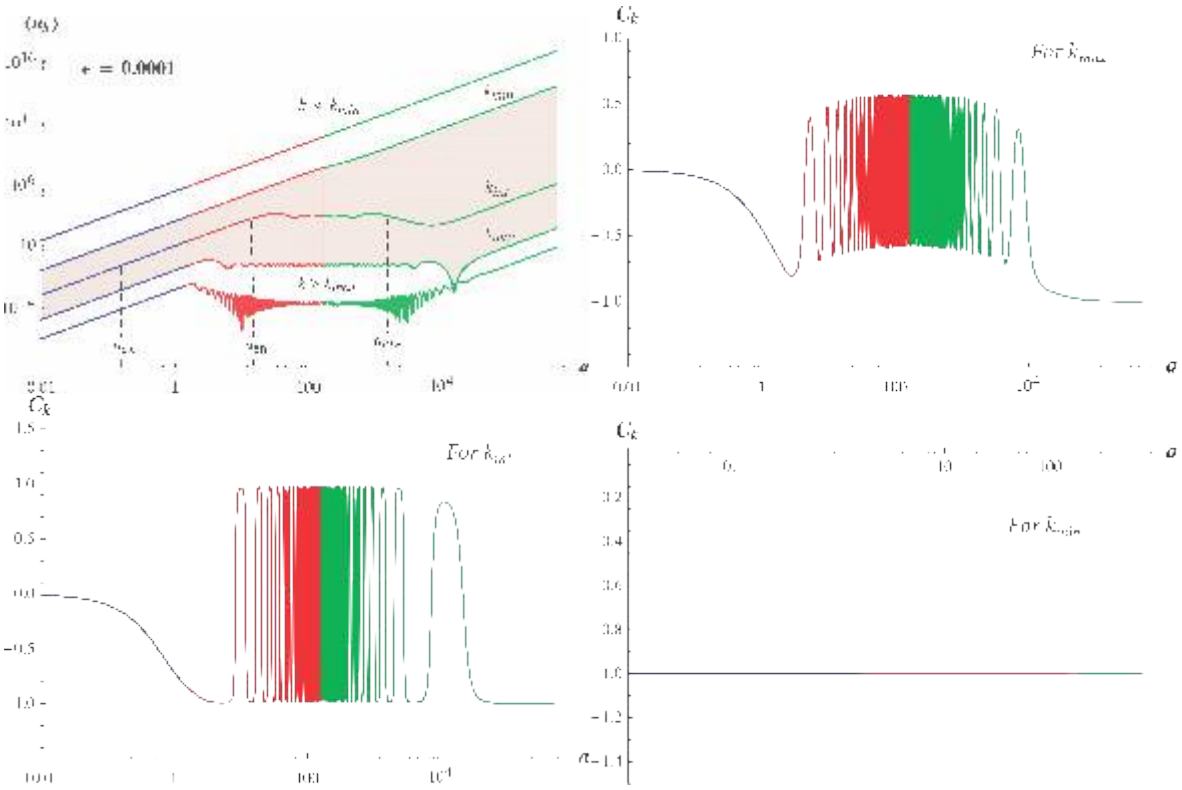

Figure 3: Evolution of the average particle number $\langle n_k \rangle$ and classicality parameter $\mathcal{C}_k$ with the scale factor for $H_\Lambda/H_{\rm inf} = \epsilon = 0.0001$ for all time sub-Hubble, intermediate (which exit the Hubble radius and re-enter in the next phase) and all time super-Hubble modes.

stringy effect might dominate over the curvature effect. Numerical bounds to different coupling parameters in various alternative gravity models have been estimated.

Chakraborty has also studied neutrino flavour oscillation in some classes of alternative gravity theories, and general equations for oscillation phases have been given. He has calculated the oscillation length and transition probability in these spacetimes, from which he has constrained parameters appearing in these alternative theories using standard solar neutrino results.

Time delay between relativistic images as a probe of cosmic censorship

Satyabrata Sahu, **Mandar Patil**, D. Narasimha and Pankaj S. Joshi have studied the time delay in successive relativistic images in gravitational lensing as a possible discriminator in various collapse end states, and hence as a probe of cosmic censorship. Specifically, both black hole and naked singularity spacetimes are considered admitting photon spheres, where an infinite number of relativistic Einstein rings can be formed at almost the same radius and naked singularity spacetimes without a photon sphere, where multiple relativistic Einstein rings can form almost up to the centre of the lens. The metrics considered to sample these scenarios are the Schwarzschild black hole, Janis-Newman-Winicour (naked singularity with photon sphere), Joshi-Malafarina-Narayan and Tolman-VI (naked singularities without photon sphere), which are a fair sample of the theoretical possibilities. It is shown that the differential time delay in the relativistic images for naked singularities without a photon sphere progressively decreases for the models as opposed to that

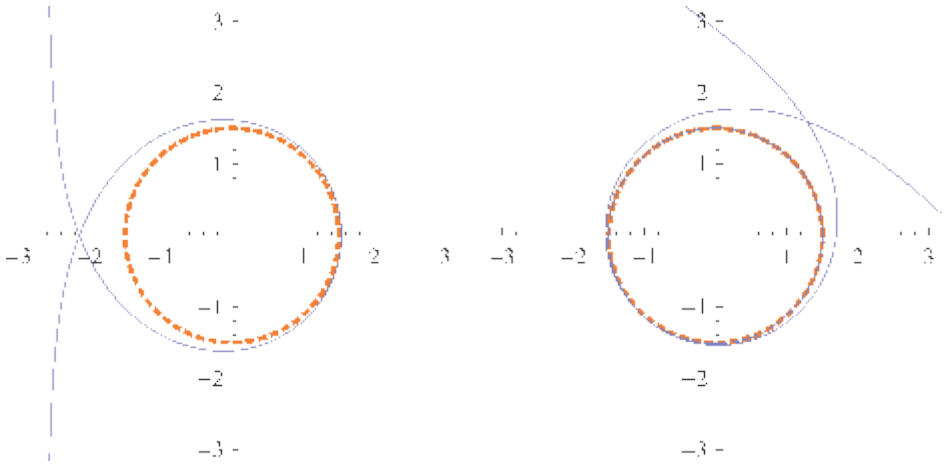

Figure 4: Schematic photon trajectory for relativistic deflection in spacetime with photon sphere with both axes plotted in Schwarzschild units (photon sphere is given by the thick orange circle; in the two-loop case the second loop is virtually indistinguishable from the photon sphere)

for black holes and naked singularities with a photon sphere, where it is known to be roughly constant. This characteristic difference in the time delay in successive images for these two cases can be potentially exploited for a source with known intrinsic variability to discriminate in these scenarios even when the images are not spatially resolved (see Figures 4 and 5).

Particle acceleration by binary black holes

Recently it has been shown that it would be possible to have collisions between the infalling particles with divergent centre of mass energy near the event horizon of extremal Kerr black hole. **Mandar Patil** and Pankaj S. Joshi have explored multi-black hole solutions from such a perspective. Majumdar-Papapetrou solution has been studied for this purpose, which represents the binary system consisting of two identical black holes. The two extremally charged black holes are in the state of equilibrium since their mutual gravitational attraction is balanced by the electrostatic repulsion. Particles following timelike geodesics that are confined to move on equatorial plane towards the axis of symmetry are considered. Particles approach the point midway between the two black holes where they undergo collision. They have shown that the centre of mass energy of collision between the particles increases with the decrease in the separation between the black holes and shows divergence in the limit where separation goes to zero. Whether or not high energy collisions can occur in the more general setting like colliding black holes, in the intermediate region when distance between the black holes is small can in principle be verified in the numerical relativity simulations. If similar results hold good in the dynamical situation then it would imply that colliding black hole would not only be emitters of gravitational radiation but also the particle accelerators to arbitrarily high energies.

Finite escape fraction for ultrahigh energy collisions around Kerr naked singularity

Mandar Patil and Pankaj S. Joshi have investigated the issue of observability of high energy collisions around Kerr naked singularity and have shown that the results are in contrast with the Kerr black hole case. They had shown earlier that it would be possible to have ultrahigh energy collisions between the particles close to the location $r = M$ around the Kerr naked singularity if the Kerr spin parameter transcends

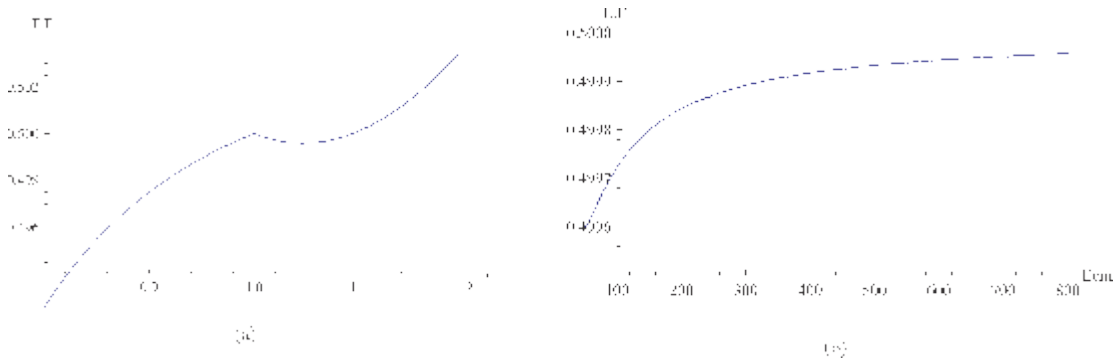

Figure 5: (a) shows the variation of escape fraction with radius. Highly energetic collisions take place around $r = 1$. Here $\epsilon = a - 1 = 10^{-8}$. The escape fraction is more or less constant and takes a value $E.F. \approx 0.5$. (b) depicts the slight increase in the escape fraction with the centre of mass energy of collision.

the unity by a small amount $a \to 1^+$. The collision is between initially ingoing particle that turns back as an outgoing particle due to angular momentum barrier and another ingoing particle. It is assumed that two massless particles are produced in such a collision and their angular distribution is isotropic in the centre of mass frame. The escape fraction, i.e., the probability for the massless particles to reach infinity is calculated. It is shown that the escape fraction is finite and approximately equal to half for ultrahigh energy collisions. Therefore, the particles produced in high energy collisions would escape to infinity providing signature of the nature of basic interactions at those energies. This result is in contract with the extremal Kerr black hole case, where almost all particles produced in high energy collisions close to the event horizon are absorbed by the black hole, thus rendering the collisions unobservable. (See Figure 5).

Observational Cosmology and Extragalactic Astronomy

Origin of S0 galaxies

The central components of late type galaxies (both lenticulars as well as spirals), referred to as "bulges" in the literature, have proved to be a mystery on many fronts. From the point of view of formation, it has been demonstrated recently that these bulges come in two flavours - the ones likely having formed through major merger like interactions, known as classical bulges, while the others likely formed through secular processes, known as pseudobulges. The demographics of the two types of bulges reveal a frequent occurrence of pseudobulges in late-type galaxies and this has been shown to be a challenge to the current model of galaxy formation and large scale structure formation in general.

Using a sample of 185 S0 galaxies, it has been demonstrated that pseudobulge hosting disks differ from classical bulge hosting disks. In continuation of this study, involving **Kaustubh Vaghmare**, Sudhanshu Barway (South African Astronomical Observatory), Smita Mathur (Ohio State University) and **Ajit Kembhavi**, this sample of S0 galaxies has been augmented by a sample of spiral galaxies, and it has been found that among the pseudobulges in the two types of galaxies, there are differences in disk properties. While, from the point of view of central surface brightness, one cannot differentiate between the pseudobulges of S0 and spiral galaxies, clear differences are found with respect to disk scale lengths. Pseudobulge hosting disks in S0 galaxies have a lower scale length than their counterparts in spirals. This finding has interesting implications on understanding pseudobulge formation processes as well as the processes responsible for the transformation of spirals into S0s.

One can consider pseudobulge hosting S0s to have started out as spiral galaxies, whose

bulges evolved secularly and later through various processes such as ram pressure stripping, and lost their spiral arms, thus, appearing today as pseudobulge hosting S0 galaxies. However, recent simulations done by various groups show that it is possible for constructing S0 galaxies whose bulges show both photometric and kinematic signatures of pseudobulges without allowing secular evolution to be a dominant process, but through minor mergers instead. Investigations are being carried out to see if one can use current observational data to favour or rule out one of the two formation scenarios.

Astronomy of transients

The ROSAT satellite conducted an all sky survey in the X-ray band leading to a catalogue comprising of 18,806 bright X-ray sources, know as the ROSAT Bright Source Catalog. Despite more than a decade having passed since this catalogue came into existence, the optical counterparts of many of these X-ray sources have not been discovered. This is mainly because of the large positional errors owing to the poor resolution of the instruments on board the ROSAT. One of the the most notable attempts to carry out this task used brightness and positional offset as two parameters to assign association probabilities. However, phenomenon leading to X-ray emission usually lead to variability in the optical band and thus, the use of variability information is crucial when associating optical counterparts with the X-ray sources. This has been made possible with systematic surveys such as the Palomar Transient Factory (PTF) survey.

Kaustubh Vaghmare, Varun Bhalerao, Devraj Pawar and Eric Bellm are in the process of constructing a machinery by which likelihoods may be assigned to the sources discovered by PTF, of being the optical counterparts to X-ray sources in the ROSAT BSC. The machinery involves using metrics of variability and photometric error information to estimate the intrinsic variability of the source and compute an association likelihood using the empirical distribution of intrinsic variabilities in the sky. The likelihood based on variability will be used with the likelihoods based on brightness and position to produce a catalogue of PTF counterparts to ROSAT BSC sources.

HI 21-cm absorption from nearby galaxies

It is well known that physical conditions in the diffuse interstellar medium (ISM) of galaxies are influenced by various radiative and mechanical feedback processes associated with in-situ star formation. Therefore, volume-filling factors of different phases of gas in a galaxy are expected to depend on its star formation history. Of particular interest is the evolution of the volume-filling factor of cold neutral medium (CNM) phase that also serves as a gaseous reservoir for star formation in galaxies. It is expected to contain an imprint of the collective outcome of all the processes that shape the star formation history of the Universe. 21-cm absorption line detected in spectra of distant quasars can be used to trace the evolution of cold atomic gas in galaxies.

Neeraj Gupta, **R. Srianand** and their collaborators (P. Petitjean, P. Noterdaeme, and S. Muzahid) have reported the detection of 21-cm absorption from foreground galaxies towards quasars, specifically $z_{gal} = 0.3120$ towards SDSS J084957.97+ 510829.0 ($z_{qso} = 0.584$; Pair-I) and $z_{gal} = 0.3714$ towards SDSS J144304.53+ 021419.3 ($z_{qso} = 1.82$; Pair-II). In both the cases, the integrated 21-cm optical depth is consistent with the absorbing gas being a damped Lyα (DLA) system. In the case of Pair-I, strong Na I and Ca II absorption lines are also detected at z_{gal} in the QSO spectrum. We have identified an early-type galaxy at an impact parameter of b$\sim$14 kpc, whose photometric redshift is consistent with that of the detected metal and 21-cm absorption lines (see Figure 6). This would be the first example of an early-type galaxy associated with an intervening 21-cm absorber. The gas detected in 21-cm and metal absorption lines on the outskirts of this luminous red galaxy could be associated with the reservoir of cold H I gas with a low level of star formation activity in the outer regions of the galaxy as reported in the literature for z $\sim$ 0.1 early-type galaxies. In the case of Pair-II, the absorption is associated with a low surface brightness galaxy that, unlike most other known quasar-galaxy pairs (QGPs), i.e., QSO sight lines passing through disks or halos of foreground galaxies, are identified only via narrow optical emission lines detected on top of the QSO spectra. Using SDSS spectra, we infer that the emission lines originate within 5 kpc of the QSO sight

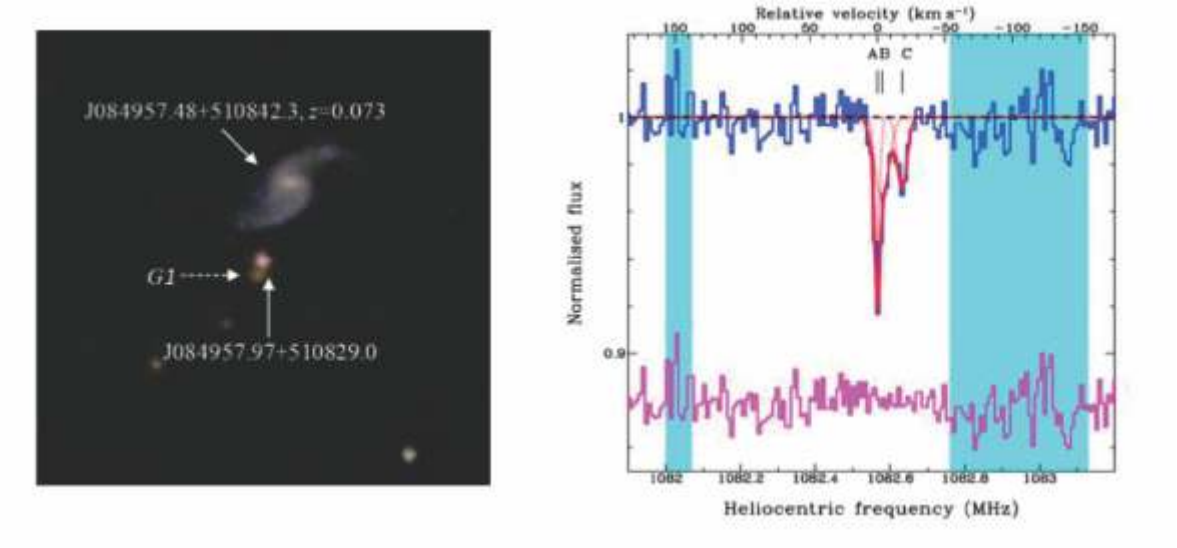

Figure 6: SDSS colour representation of QGP J0849+5108. The galaxy J084957.48+510842.3 ($z_{gal} = 0.073$) situated at $\sim 14''$ (b $\sim$19 kpc) north of the radio source is a member of an interacting pair of galaxies. The galaxy "G1" is the early-type galaxy associated with the 21-cm absorption detected at z = 0.3120 shown in the right panel. Origin of the velocity scale given at the top is defined with respect to the maximum of 21-cm optical depth. Shaded regions mark the redshift range affected by radio frequency interference. This discovery is part of an ongoing systematic survey to search for 21-cm absorption and molecular absorption lines in nearby galaxies using the Giant Metrewave Radio Telescope (GMRT), the Karl G. Jansky Very Large Array (JVLA) and the Westerbork Synthesis Radio Telescope (WSRT).

line. The measured 21-cm optical depth can be reconciled with the N(H I) we derive from the measured extinction if either the H I gas is warm or the extinction per hydrogen atom in this galaxy is much higher than the mean value of the Small Magellanic Cloud. Finally, using a sample of 9 QGPs with 21-cm absorption detection from our observations and literature, we report a weak anti-correlation between the 21-cm optical depth and galaxy impact parameter.

Variability in low ionization broad absorption line outflows

Vivek M., R. Srianand, Vijay Mohan and their collaborators have presented results of their 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 $0.2 \leq z_{em} \leq 2.1$ using the 2-m telescope at IUCAA Girawali Observatory over a time-scale of 10 d to 7.69 years in the QSO's rest frame. Spectra were analysed in conjunction with photometric light curves from Catalina Real-Time Transient Survey. Long time-scale (i.e., ≥ 1 year) absorption line variability is seen in eight cases (36 per cent systems) while only four of them (i.e., 18 per cent systems) show variability over short time-scales (i.e., ≤ 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 in LoBAL QSOs 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 have also 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.

A study of low-metallicity DLAs at high redshift and C II* as a probe of their physical conditions

Rajeshwari Dutta, R. Srianand, Hadi Rahmani Bayegi and their collaborators have presented a detailed high spectral resolution (R $\sim$ 40, 000) study of five high-z damped Lyman-α 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 $z_{abs} = 4.20287$ 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 $z_{abs} = 2.34006$ towards J0035-0918 has been claimed to be the most carbon-enhanced metal-poor DLA. However, they have shown that 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 has been 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 have concluded 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.

Constraining the variation in the fine-structure constant using SDSS DR7 quasi-stellar object spectra

Hadi Rahmani Bayegi, R. Srianand and a project student N. Maheshwari (from IIT, Mumbai), have reported a robust constraint on the possible variation of the fine-structure

constant, $\alpha = e^2/\hbar c$, obtained using O III$\lambda\lambda$ 4959, 5007 nebular emission lines from quasi-stellar objects (QSOs). They have found $\Delta\alpha/\alpha = -(2.1 \pm 1.6) \times 10^{-5}$, based on a well-selected sample of 2347 QSOs from the Sloan Digital Sky Survey Data Release 7 with $0.02 < z < 0.74$. Their result is consistent with a non-varying at a level of 2×10^{-5} over approximately 7 Gyr. This is the largest sample of extragalactic objects yet used to constrain the variation of α. While this constraint is not as stringent as those determined using the many-multiplet method, it is free from various systematic effects. A factor of 4 improvement in $\Delta\alpha/\alpha$ achieved here compared to a previous study is consistent with what is expected based on the sample used here, which is a factor of 14 times larger. This suggests that errors are mainly dominated by statistical uncertainty. They have also found that the ratio of transition probabilities corresponding to the O III λ5007 and λ4959 lines is 2.933±0.002, in good agreement with the measurements of the National Institute of Standards and Technology.

The UVES large programme for testing fundamental physics - II. Constraints on a change in μ towards quasar HE 0027-1836

Hadi Rahmani Bayegi, R. Srianand and their collaborators have reported an accurate analysis of the H_2 absorption lines from the $z_{abs} \sim 2.4018$ damped Lyα system towards HE 0027-1836 observed with the Very Large Telescope Ultraviolet and Visual Echelle Spectrograph (VLT/UVES) as a part of the European Southern Observatory Large Programme. The UVES large programme for testing fundamental physics to constrain the variation of proton-to-electron mass ratio, $\mu = m_p/m_e$. They have performed cross-correlation analysis between 19 individual exposures taken over three years and the combined spectrum to check the wavelength calibration stability. They have noticed the presence of a possible wavelength-dependent velocity drift especially in the data taken in 2012. They have used available asteroids spectra taken with UVES close to our observations to confirm and quantify this effect and considered single- and two-component Voigt profiles to model the observed H_2 absorption profiles. Both linear regression analysis and Voigt profile fitting, where $\Delta\mu/\mu$ is explicitly considered are additional fitting parameter. The two-component model is marginally favoured by the statistical indicators and they get $\Delta\mu/\mu = -2.5 \pm 8.1_{stat} \pm 6.2_{sys}$ ppm. When they apply the correction to the wavelength-dependent velocity drift, they find $\Delta\mu/\mu = -7.6 \pm 8.1_{stat} \pm 6.3_{sys}$ ppm. It will be important to check the extent to which the velocity drift they notice in their study is present in UVES data used for previous $\Delta\mu/\mu$ measurements.

How do classical bulges get their angular momentum ?

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

In an ongoing collaboration with Ortwin Gerhard and Inma Martinez-Valpuesta, **Kana Saha** has proposed a mechanism based on the resonant interaction of classical bulge stars with a bar that forms in the disk as result of disk instability. This work is based on the self-consistent N-body simulation of a set of initially axisymmetric disk galaxies with pre-existing non-rotating classical bulges of various sizes and masses. They have shown that as the disk forms a bar, it interacts with the classical bulge stars primarily through resonances but also via chaotic orbits. As a result, the classical bulge gains a significant fraction of angular momentum and spin up to their corresponding oblate isotropic rotator model in less than half the Hubble time (see Figure 7). Further analyses in this direction show that those classical bulges, for which the bulge sizes are either equal to the bar size or match within ±25% of their bar sizes, are spun up close to an isotropic rotator of same ellipticity. It is shown that too compact or too diffuse classical bulges do not gain significant angular momentum emitted by the bar, and thereby rotate only slowly. Their results indicate that some classical bulges in spiral galaxies might have started rotating through these processes or atleast have gained a good fraction of angular momentum in this way.

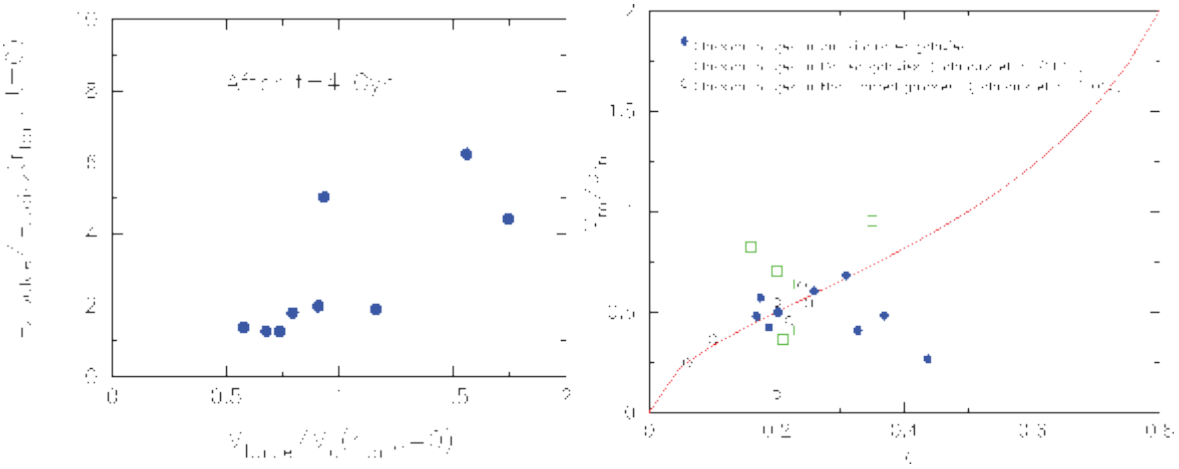

Figure 7: The left panel shows the gain of angular momentum by the initially non-rotating classical bulges at the end of 4 billion year. On the right panel, we have shown the famous Kormendy plot, which relates the ratio of rotational velocity to random velocity versus apparent ellipticity. Some of our classical bulges start rotating like the oblate isotropic rotator of same ellipticity after 4 billion year. Our simulated bulges are compared to a recent observed bulges as mentioned in the figure.

Angular momentum transport and evolution of lopsided galaxies

The surface brightness distribution in the majority of stellar galactic discs falls off exponentially. Often what lies beyond such a stellar disc is the neutral hydrogen gas whose distribution also follows a nearly exponential profile at least for a number of nearby disc galaxies. Both the stars and gas are known to host lopsided asymmetry especially in the outer parts of a galaxy. The role of such asymmetry in the dynamical evolution of a galaxy has not been explored so far, in particular whether it facilitates in driving gas inflow as eventually required for the AGN fueling.

Following Lindblad's original idea of kinematic density waves, **Kanak Saha** and his collaborators have shown that the outer part of an exponential disc is ideally suitable for hosting lopsided asymmetry. They have computed the transport of angular momentum in the combined stars and gas disc embedded in a dark matter halo (see Figure 8). They have shown that in a pure star and gas disc, there is a transition point where the free precession frequency of a lopsided mode, $\Omega - \kappa$, changes from retrograde to prograde, and this in turn reverses the direction of angular momentum flow in the disc leading to a unphysical result. Further, it has been shown that this problem is overcome in the presence of a dark matter halo, which sets the angular momentum flow outwards as required for disc evolution, provided the lopsidedness is leading in nature. This can facilitate an inflow of gas from outside, perhaps through the cosmic filaments. This work has been carried out in collaboration with Chanda J. Jog.

Thick disk formation via complex instability

Thick disks are believed to be one of the structural component, which dominates the stellar light high above the disk midplane in spiral galaxies including our Milky Way. Thick disks are kinematically hotter than thin disk and their origin is currently under debate.

Using a very high resolution N-body simulation, **Kanak Saha** (in collaboration with Daniel Pfenniger) has shown that a part or whole of the thick disk might be forming via the complex instability in the presence of a strongly growing bar. In general, in a galaxy with steadily rotating bar potential, the stationary points are the Lagrangian points, which are known to linearly stable (especially, L_4 and L_5 placed along the minor axis of the bar) if the bar is weak and slowly rotating. However, as the strength and pattern speed of the bar increase, these

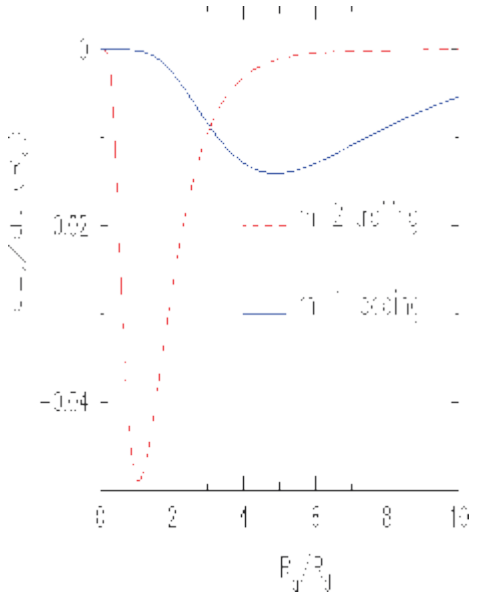

Figure 8: The inner part of the galaxy is dominated by m = 2 perturbation, e.g., bars, spirals, which dominate the angular momentum transport there. However, m = 2 fades away in the outer parts leaving m = 1 lopsided perturbation as the only dominant component, which can exert significant torque on the outer parts.

Lagrangian points become unstable and sometimes go complex unstable. As a consequence, the orbits becomes readily chaotic and chaotic diffusion starts dominating. In fact, in barred galaxies a large fraction of orbits are chaotic and perhaps for some, the origin lies in this kind of instability. Such strong diffusion pushes the stars far off the midplane and at larger radii in the galaxy. **Saha** and his collaborators have shown that these stars belong to a kinematically hot population and form the thick disk component. Figure 9 and Figure 10 show the evolution of a few thousand randomly selected stars around the Lagrangian point (L_4) according to their Jacobi energy ($E_J = E - \Omega_B L_z$, where Ω_B is the bar pattern speed).

Gravitational Waves

Gravitational waves (GW) will not only allow us to test the predictions of general relativity in regions of strong gravity, but will also serve as a tool to expand our understanding of the Universe. Direct detection of GW is expected by the end of this decade by an international network of advanced (second generation) laser interferometric detectors. Presently, a significant amount of effort is being devoted by the GW research community in developing algorithms and data analysis pipelines to efficiently search for GW signals in noisy data. Compact Binary Coalescences (CBCs) are expected to be the most promising sources for the first detections because their rates are favourable, and their phases can be modeled to a very high accuracy, so that matched filtering can be used to search for them. Gravitational waves, however, can probe a much wider range of known and (so far) unknown sources, where the phase evolution in most of the cases is unmodeled or ill-modeled. A Stochastic Gravitational Wave Background (SGWB) is one of such sources, which can be created by overlapping GW signals from unresolved astrophysical sources in the nearby anisotropic universe. A weaker isotropic SGWB is also expected from GW produced in the early universe. Gravitational wave researchers in IUCAA work on astrophysical and cosmological aspects of both types of sources and on devising methods for detecting them.

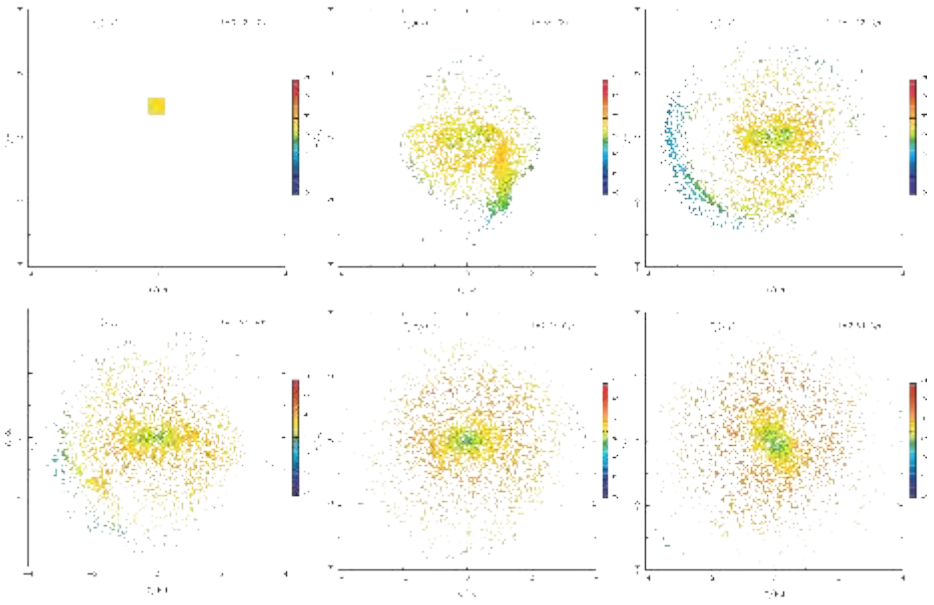

Figure 9: The plot showing the distribution of 3091 stars randomly selected around L_4 at $t \sim 0.2$ Gyr (top left panel) in the X-Y plane of the disk. The stars are colour coded according to their Jacobi energy. Subsequent panels show the distribution of the same number of particles at different times during the evolution.

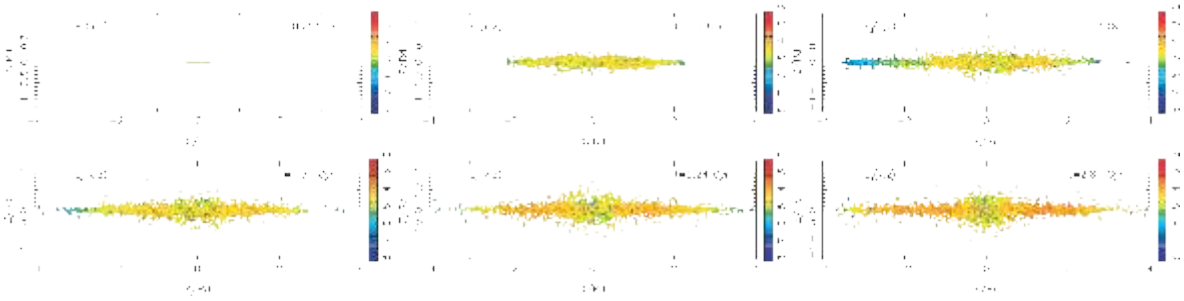

Figure 10: Same as in Fig 9 but in the x - z (edge-on view) plane of the galaxy model. At $t \sim 0.2$ Gyr, all the particles have nearly same E_J centred around L_4 and confined very near the midplane $|z| < 0.01 R_d$. In the subsequent panels, the average height of the particles rises by more than a factor of 20. Stars with minimum Jacobi energy lie very close to the midplane.

A localised source of stochastic GW background vs. Confusion noise: Olbers paradox

Nairwita Mazumder, **Sanjit Mitra** and **Sanjeev Dhurandhar** have shown that a targeted search for a localised source of a SGWB in the nearby universe can be highly efficient as compared to the statistically isotropic background created by the rest of the universe. This problem is similar to solving the Olbers paradox for electromagnetic astronomy, but more complicated as the detection efficiency strongly depends on the integrated spectra. They have computed the combined spectrum of the mean isotropic background for different cosmologies by integrating over different redshifts. It has been numerically shown that a targeted search performs better than the isotropic search if the constituting sources are predominant at low redshifts. Considering different baselines of the existing GW detector network, they have showed that longer baselines perform better at higher frequencies. (see Figure 11)

Measuring neutron star ellipticity with measurements of the stochastic gravitational wave background

Galactic neutron stars are a promising source of GW in the analysis band of detectors such as LIGO and Virgo. Previous searches for GW from neutron stars have focused on the detection of individual neutron stars, which are either nearby or highly non-spherical. However, the population of spinning aspherical neutron stars in our galaxy or nearby galaxy clusters, such as Virgo, are expected to produce of a stochastic GW background arising from the superposition of signals from individual neutron stars. What can the observation of that background tell us which the detection of some of the individual signals cannot? With this question in mind, **Sukanta Bose**, collaborated with his former Ph.D. student Dipongkar Talukder, and Eric Thrane and Tania Regimbau, to estimate the single-sigma sensitivity of current and planned GW observatories to the average neutron star ellipticity ϵ as a function of the number of in-band galactic neutron stars $N_{\rm tot}$. For the plausible case of $N_{\rm tot} = 53,000$ neutron stars, and assuming one year of observation time with colocated initial LIGO detectors, they have found it to be $\sigma_\epsilon = 2.5 \times 10^7$, which is comparable to current bounds on some nearby neutron stars. (The current best 95 per cent upper limit is $\epsilon = 7 \times 10^8$.) It is unclear if advanced LIGO can significantly improve on this sensitivity using spatially separated detectors. For the proposed Einstein Telescope, they have estimated that $\sigma_\epsilon = 2.6 \times 10^{10}$. Finally, they have shown that stochastic measurements can be combined with measurements of individual neutron stars in order to estimate the number of in-band Galactic neutron stars. which is still an unknown quantity (see Figure 12).

Towards finding gravitational wave signals from progenitors of short hard gamma-ray bursts and orphaned afterglows

With multiple observatories and missions being planned for detecting orphaned afterglows associated with gamma-ray bursts (GRB), it is becoming increasingly important that data analysis strategies be developed for searching their possible counterpart signals in the data of GW detectors in the advanced detector era. This is especially attractive since short hard gamma-ray bursts (SGRB) may have compact binary coalescences involving neutron stars (CBCNS) as their progenitors, which emit GW. Joint electromagnetic (EM) and GW observations of these objects will enrich our understanding of their beaming, energetics, galactic environment, and shed light on a host of other outstanding questions related to them. **Sukanta Bose** and his former PhD student Shaon Ghosh have recognized some of the astrophysical factors that determine what fraction of CBCNS sources can generate orphaned afterglows. Pipelines already exist that target the sky-position and time of occurrence of SGRB, known from EM observations, to search for their counterparts in GW detector data. Modifying them to analyze extended periods of time in the GW data in the past of the afterglow detection, while targeting a single sky-position, can search for GWs from the common progenitor. They have assessed the improvement in GW detectability (see Figure 13) to be had from utilizing the sky-position information. They also have proposed a method for improving the detection efficiency of targeted searches of GW signals from the putative CBCNS sources of afterglows and short gamma ray bursts

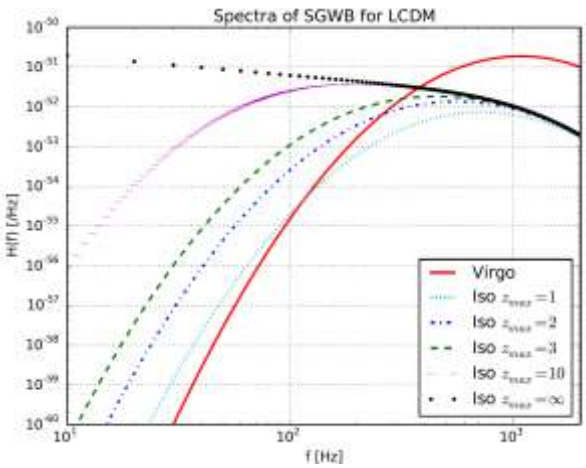

Figure 11: The figure compares the power spectral density (PSD) of stochastic gravitational wave backgrounds generated by the estimated ensemble of milli-second pulsars in the Virgo cluster with those generated by all the sources in an LCDM universe within the Virgo solid angle for different redshift cut offs. Clearly the Virgo cluster dominates at the higher frequencies, while all the other sources dominate the lower frequencies due to cosmological redshift.

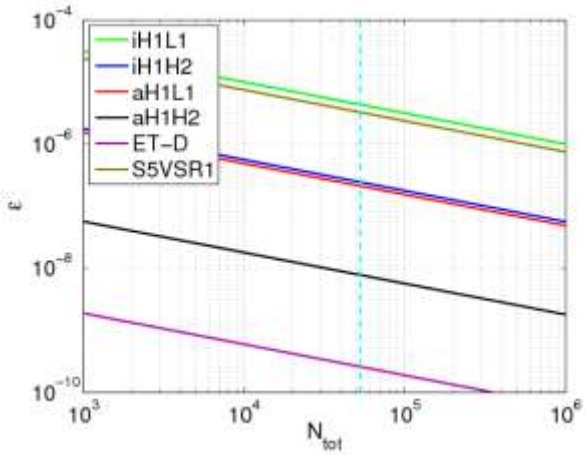

Figure 12: One-sigma sensitivity curves in the ϵ - $N_{\rm tot}$ plane. The parameter space above a curve will, on average, produce a signal with a signal-to-noise ratio greater than unity. **Sukanta Bose** and his collaborators have shown theoretical sensitivity curves (assuming one year of observation time) for initial LIGO-Hanford-4km - LIGO-Livingston-4km (iH1L1), initial LIGO-Hanford-4km - LIGO-Hanford-2km (iH1H2), same detector pairs with Advanced sensitvity (i.e., aH1L1, aH1H2), and the Einstein Telescope (ET-D). While efforts are underway to move H2 to India, we have included the H1H2 detector pair for illustrative purposes. They have also shown the measured sensitivity obtained in previously published results using data from both initial LIGO and Virgo [J. Abadie et al., Phys. Rev. D85, 122001 (2012)]. The vertical dashed cyan line indicates $N_{\rm tot} = 52{,}800$. It is interesting to note that once we are able to measure the ellipticities of individual neutron stars and have a better idea about the average ellipticity of the neutron star population in the Galaxy, we can use the above figure to infer the total number of neutron stars in the Galaxy.

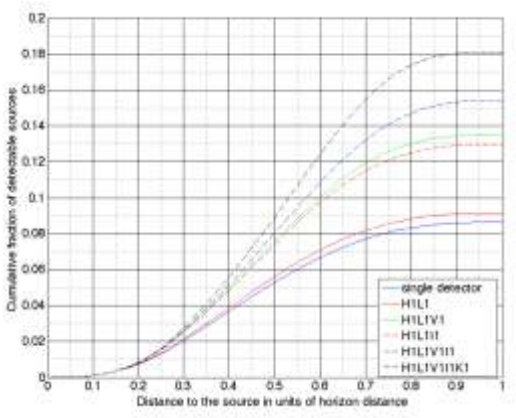

Figure 13: The cumulative fraction of detectable compact binary coalescence (CBC) sources in a spherical volume of radius r plotted as a function of r. The sources are distributed uniformly in volume and are oriented randomly. This fraction attains a maximum value of 8.65% for the network of three detectors involving LIGO-Hanford (H1), LIGO-Livingston (L1), and Virgo (V1), when r reaches the horizon distance, which is the maximum distance at which a binary neutron star system is detectable in a network at a signal-to-noise ratio of 8. As shown by **Sukanta Bose** and Shaon Ghosh above, the detectability of sources improves appreciably with the inclusion of LIGO-India (I1) and the Japanese detector KAGRA (K1) (the dashed curves).

in the presence of errors in detector calibration or CBCNS waveform models used in the search. They have shown that the improvement arises from searching in a wider patch of the sky even when the sky-position is known accurately from EM observations and utilizes the covariance of the errors in waveform parameters with those in the sky position.

Effect of sine-Gaussian glitches on binary coalescence searches

S. V. Dhurandhar and collaborators have investigated the effect of an important class of glitches occurring in detector data on matched filter searches of GW from coalescing binaries in advanced detectors. The glitches are modeled as sine-Gaussians. They can produce triggers with significant time-delays and have important bearing on veto procedures. The authors have provided approximated analytical estimates of the trigger signal-to-noise ratio (SNR) and time-lags as a function of the parameters of the sine-Gaussian and the inspiral filter. The analytical predictions are validated numerically. The time-lag and the SNR of the trigger are recovered numerically (see Figure 14). Although the approximations do not cover the parameter space individually, they complement each other and together effectively cover the parameter space.

Improved coincident and coherent detection statistics for searches for gravitational wave ringdown signals

Black holes perturbed, e.g., by infalling objects, emit GW signals, called ringdowns. These signals are damped sinusoids, whose frequency and damping constant can be used to measure a black hole mass and spin. The detection of these signals in upcoming and future GW observatories will help to offer clues on the distribution of the masses and spins of these black holes. It will also help us probe whether most stellar mass black holes in our galaxy are close to maximally spinning or not. To improve the detectibility of the ringdown signals (see Figure 15), Dipongkar Talukder, **Sukanta Bose**, Sarah Caudill and Paul T. Baker have utilized the output from a matched-filter analysis pipeline to devise a statistic that is more powerful than those proposed in the past in identifying them in a coincidence analysis of real data with transient noise artifacts from two or three detectors. Their statistic addresses the non-Gaussianity of the data without the use of an additional signal-based

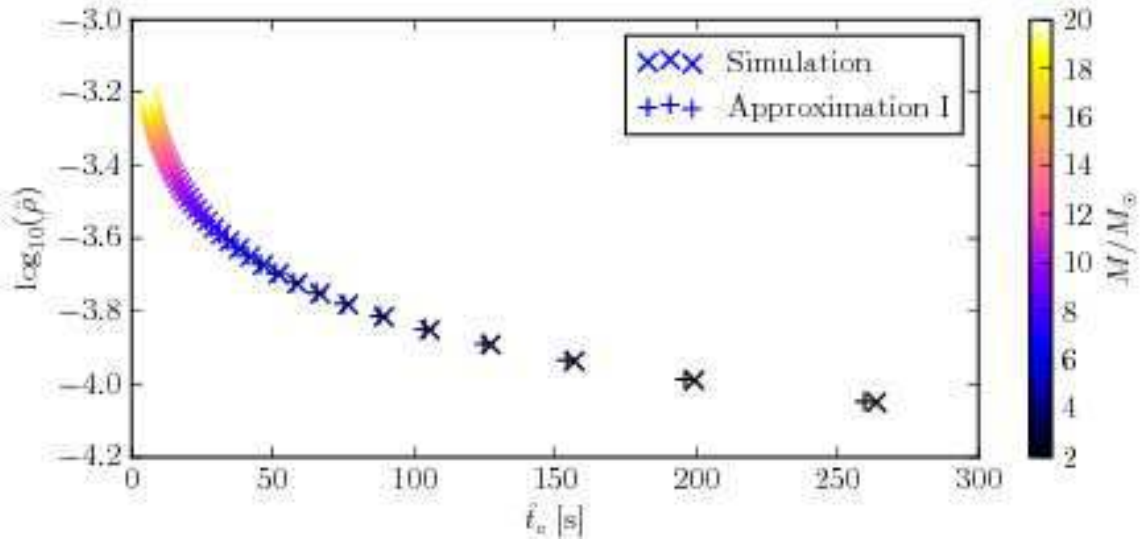

Figure 14: Cluster of triggers generated by a template bank corresponding to a sine-Gaussian glitch with $t = 0$, $f_0 = 20$Hz and $Q = 20$. The bank consists of fifty 3.5 PN equal-mass waveforms with total mass M uniformly spaced between 2 and 20 solar masses. The cluster extends well after the glitch with lowest mass templates producing triggers minutes after the glitch.

waveform consistency test. They also have developed coherent network statistics to check for consistency of signal amplitudes and phases in the different detectors with their different orientations and signal arrival times. They have found that the detection efficiency can be improved at least by a few tens of per cent by applying these multidetector statistics primarily because of the ineffectiveness of single detector based discriminators of non-stationary noise, such as the chi-square test, in the case of ringdown signals.

Preparations for detecting and characterizing gravitational wave signals from binary black hole coalescences

A few years ago members of the numerical relativity and GW astrophysics communities have joined forces to launch a collaborative effort, called the Numerical INJection Analysis (NINJA) to study the ability of data analysis search pipelines to detect GW signals from merging binary black holes, and measure their parameters with upcoming GW observatories. In the second NINJA project, NINJA-2, several complete binary black hole hybrid waveforms consisting of a numerical portion modelling the late inspiral, merger, and ringdown stitched to a post-Newtonian portion modeling the early inspiral phase were employed. **Sukanta Bose** and his former student Thilina Dayanga have collaborated to evaluate how well the waveforms obtained from the effective one-body formalism and calibrated against Numerical Relativity (NR), namely, "EOBNR", perform in detecting GW signals from non-spinning binary black hole (BBH) coalescences. NINJA-2 NR-based signals that are available in the public domain have been injected in simulated Gaussian, stationary data prepared for three LIGO-Virgo detectors with early advanced LIGO sensitivities. A total of 2,000 such signals from 20 NR-based signal families were injected in a two-month long data set. The all-sky, all-time compact binary coalescence (CBC) search pipeline was run along with an added coherent stage to search for those signals. They have found that the EOBNR templates are only slightly less efficient (by a few per cent) in detecting non-spinning NR-based signals than in detecting EOBNR injections. On the other hand, the coherent stage improves the signal detectibility by a few per cent over a coincident search. These findings augur well for the readiness of our GW

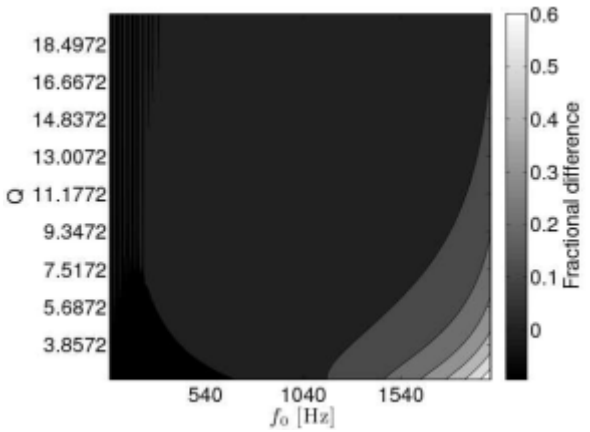

Figure 15: Contours of the fractional difference of sine and cosine phases of the two-phase ringdown template. The colour bar represents the fractional difference. Gravitational wave signals from the ringdown of a black hole can be modeled as damped sinusoids, with a central frequency f_0 and a time constant determined by the quality factor Q. Until recently, GW searches in LIGO-Virgo data have employed damped sinusoid templates with a single phase (e.g., the "cosine" phase) to search for ringdown signals in their data. **Sukanta Bose** and his collaborators have shown that while such single-phased searches have been adequate for most of the (Q, f_0) parameter space, neglecting the templates that have been 90 degrees out of phase (i.e., the "sine" phase) in these searches could result in significant loss in signal detectibility at low Q and high f_0, which is the bottom-right region in the above figure.

search pipelines in analyzing data from advanced interferometers once they start observing by late 2015.

Searching for systematics in type IA supernovae

A remarkable property of our Universe is that it is accelerating. The precise cause of cosmic acceleration is presently unknown but might rest in the presence of the cosmological constant or some other form of 'Dark Energy' (DE) capable of violating the strong energy condition. The main evidence for cosmic acceleration currently comes from two types of data sets:

(i) Those probing the luminosity distance d_L, by observing the flux $\mathcal{F}$, of type Ia supernovae of given luminosity L through:

$$\mathcal{F} = \frac{L}{4\pi d_L^2} \ .$$

(ii) Those based on the angular diameter distance d_A to a source of spatial size d, via the relation:

$$\Delta\theta = \frac{d}{d_A} \ .$$

Remarkably, for a wide range of cosmological models, the two distances are related through the *cosmic duality relation* (CDR):

$$d_L = (1+z)^2 d_A \ .$$

Since CDR follows simply from: (i) the requirement that sources and observers be connected via null geodesics in a Riemannian spacetime, (ii) the phase-space conservation of photons; therefore, it could well be that the cosmic duality relation is an *exact principle in nature*. If this is the case, then a violation of the cosmic duality relation would signal to the presence of hitherto undetected systematics in data sets relating either to d_L or to d_A (or to both).

Arman Shafieloo, Majumdar, A. Starobinsky and **Varun Sahni** have compared two different probes of the expansion history of the universe: Type Ia supernovae and galaxy clusters. The model independent method, which they have proposed searches for inconsistencies between SNIa and galaxy cluster data sets *independently* of any a-priori assumptions about the nature of dark energy. If detected, such an inconsistency would imply the presence of systematics in either of the two data sets. Simulating observations based on expected JDEM supernovae data and X-ray eROSITA + SZ Planck cluster data, they

have shown that their method allows one to detect systematics with high precision, and without advancing any hypothesis about the nature of dark energy.

Reconstructing dark energy using gravitational waves from standard sirens

Standard candles in the form of type Ia supernovae (SNIa) and standard rulers such as baryon acoustic oscillations (BAO) observed in the clustering of galaxies, have played a key role in garnering support for the accelerating universe hypothesis. A complementary probe of the expansion history is available in the form of gravitational radiation emitted from compact binary objects such as neutron star - neutron star (NS-NS) binaries, neutron star - black hole (NS-BH) binaries, or black hole - black hole (BH-BH) binaries.

Indeed, it appears that if the underlying physics behind gravitational radiation emitted by a NS-NS binary is well understood, then the luminosity distance to a given redshift D_L, can be established to a (intrinsic) precision of about 2%, making this binary an excellent *standard siren*.

Future space-based gravity wave experiments such as the Big Bang Observatory (BBO), with their excellent projected angular resolution, will measure the luminosity distance to a large number of gravitational wave (GW) sources to high precision. The redshift of the single galaxies in the narrow solid angles can then provide the redshifts of the GW sources (standard sirens). Tarun Saini, Maryam Arabsalmani and **Varun Sahni** have shown that identifying even a small number of GW source galaxies furnishes a rough distance-redshift relation, which could be used to further resolve sources that have multiple objects in the angular beam. This idea is based on a self-calibrating iterative scheme which works in conjunction with Monte-Carlo simulations to determine the luminosity distance to GW sources with progressively greater accuracy. The iterative scheme, developed by them allows one to determine the equation of state of dark energy to within an accuracy of a few per cent for a gravity wave experiment possessing a beam width an order of magnitude larger than BBO. This is achieved with no prior information about the nature of dark energy from other data sets such as SN Ia, etc.

Resurrecting power law inflation in the light of Planck results

It is well known that a canonical scalar field with an exponential potential can drive power law inflation (PLI). However, the tensor-to-scalar ratio in such models turns out to be larger than the stringent limit set by recent Planck results. Sanil Unnikrishnan and **Varun Sahni** have proposed a new model of power law inflation, for which the scalar spectra index, the tensor-to-scalar ratio and the non-Gaussianity parameter $f_{\rm NL}^{\rm equil}$ are in excellent agreement with Planck results. Inflation, in this model, is driven by a non-canonical scalar field with the Lagrangian:

$$\mathcal{L}(X,\phi) = X\left(\frac{X}{M^4}\right)^{\alpha-1} - V(\phi),$$

where α is dimensionless while M has dimensions of mass. For $\alpha = 1$, the above equation reduces to the usual canonical scalar field Lagrangian $\mathcal{L}(X,\phi) = X - V(\phi)$. A simple extension of this model resolves the graceful exit problem, which usually afflicts models of power law inflation.

Figure 16 shows that this new power law inflation model is in excellent agreement with recent Planck observations of anisotropies in the cosmic microwave background (CMB).

A no-boundary proposal for braneworld perturbations

A. Viznyuk, Y. Shtanov and **Varun Sahni** have proposed a novel approach to the problem of cosmological perturbations in a five dimensional braneworld model. They have focussed on a spatially closed brane that bounds the interior four-ball of the bulk space. Boundary conditions in the bulk now become regularity conditions for the metric everywhere inside the four-ball. In this approach, there is no spatial infinity or any other boundary in the bulk space. Hence, this setup is called a *no-boundary proposal*. Employing the Mukohyama master variable, they have demonstrated that the effects of non-locality on brane perturbations may be ignored if the brane is marginally closed. In this case, there arises a relation that closes the system of equations for perturbations on the brane. Perturbations of pressureless matter and dark radiation can now be described by a system of coupled second-order

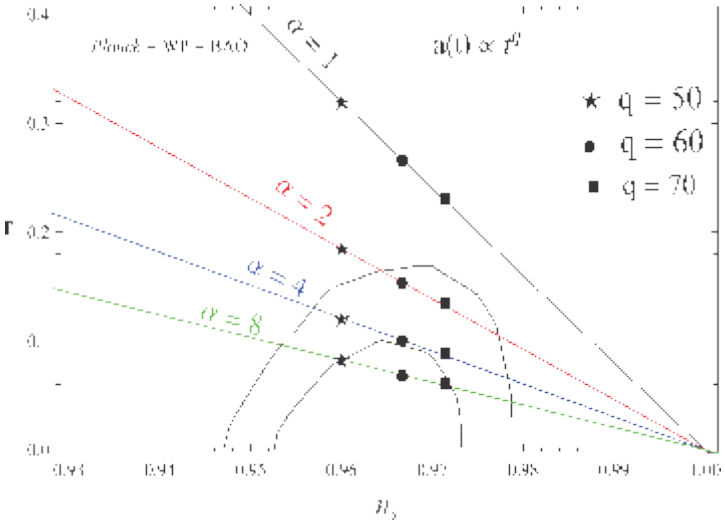

Figure 16: CMB constraints on power law inflation, $a(t) \propto t^q$, driven by the *inverse power law* potential $V(\phi) \propto \phi^{-s}$. The spectral index n_S and the tensor-to-scalar ratio r are shown for different values of the parameter α in (). The inner and outer contours correspond to 1σ and 2σ confidence limits obtained using the *Planck* + WP + BAO data. The non-canonical version ($\alpha > 1$) of PLI is in good agreement with CMB observations.

differential equations. Remarkably, this system can be exactly solved in the matter-dominated and de Sitter regimes.

This work, thus resolves a *long standing problem* in braneworld cosmology.

Cosmic Microwave Background

The Cosmic Microwave Background (CMB) anisotropy and polarisation research programme led by **Tarun Souradeep** and **Sanjit Mitra** has been continuing its unique contribution from IUCAA to the upcoming Planck results. The uniqueness comes from being the only Planck group with data rights from a nation that has made no financial contribution to the Planck mission. Increasingly more attention is being paid to emerging avenues of fruitful research on subtle cosmic signatures, often referred to as 'CMB anomalies' following IUCAA team's work using BipoSH representation that has provided strong support for the intriguing hemispherical anomaly highlighted in the Planck cosmology results announced on March 21, 2013. As a Planck scientist, **Mitra's** work has played an important role in modeling and mitigating subtle but critical systematic effect of inevitable imperfections in experimental beam response in extracting CMB polarisation information.

Statistical isotropy of the Planck CMB sky

The Bipolar Spherical Harmonic (BipoSH) representation proposed a decade back has been steadily established in the cosmology community as the most robust and natural measure of violation of statistical isotropy (SI) in the CMB anisotropy. As a core team, **Tarun Souradeep**, **Sanjit Mitra** and with graduate student **Aditya Rotti** have continued the contribution from the IUCAA group in carrying out a BipoSH analysis of the CMB temperature, and now, polarisation maps. The IUCAA team is extending its participation in the Planck collaboration using the BipoSH representation to other subtle feature such as the effect of known motion with respect to cosmic reference frame. Apart from SI violation of primordial origin weak lensing of CMB due the large scale structures (LSS) in the distribution of matter along the path of the photons generates measurable non-zero BipoSH coefficients, and is part of the ongoing studies.

Studies of SI violation and their measurement requires fast and reliable generation of random samples of non-SI CMB sky maps. **Suvodip Mukherjee** has developed and implemented a method known as, CoNIGS (Code for Non-Isotropic Gaussian Sky), that allows generation of Monte Carlo sample CMB sky that has given angular power spectrum and specific non-zero BipoSH spectra. This useful method, based on a very judicious use of Cholesky decomposition, has been published, and is now extensively used in a number of other works.

Systematic effects in the CMB observations can also lead to SI violation signal. In the hunt for a truly cosmic, possibly primordial, SI violation signal, it is important to identify, measure and correct for other effects that contaminate these measures. Building on the many years of work on modeling the inevitable non-circular distortions in the response beam of CMB experiments by **Mitra** and **Souradeep**, and a challenging team effort, involving **Nidhi Joshi-Pant**, **Santanu Das** and **Rotti** have developed an entire pipeline that can carry out full blown simulations of the CMB sky scanned by non-circular beams and quantify the effects within BipoSH representation. In particular, **Joshi-Pant** has developed the formalism for BipoSH representation of CMB maps on incomplete sky due to galactic and point source mask, which has been implemented for carrying out minimum variance estimation measurements of various non-statistical isotropy effects on data sets by **Pavan Aluri** and **Rotti**.

Measuring our local motion in the cosmic rest frame using CMB sky

It is well know from the CMB dipole anisotropy measured in early 70s that we are in motion at 369 km/s with respect to the cosmic reference frame. Recently, the Planck collaboration has shown that its high angular resolution, full sky, measurements allow a completely independent confirmation of this motion by picking up the subtle violation of statistical isotropy of CMB temperature map. **Suvodip Mukherjee**, undergraduate project student Aritra De (NISER, Bhubaneswar) and **Tarun Souradeep** have forecasted a study of the measurability of this effect using the statistical isotropy violation in up coming CMB polarisation maps from Planck in the near future and a proposed future CMB mission PRISM. They have shown that a mission like PRISM will allow a very clear detection of this effect from the CMB polarisation maps providing yet another independent confirmation of our local motion. Figure shows the forecast sensitivity plots of our local motion for different CMB polarisation measurements expected in near future from Planck and more distant future CMB mission such as PRISM.

Late universe from CMB measurements

One of the important open questions in current cosmology is an understanding of the nature of dark energy. All observations till date are satisfactorily consistent with dark energy being actually the cosmological constant. **Santanu Das** and **Tarun Souradeep** have explored the possibility that the deficit of power in large angle CMB fluctuations could, in fact, be a signature of non-trivial nature of dark energy. They have demonstrated that exotic forms of dark energy can lead to suppression of power at large angular scales through the integrated Sachs-Wolfe effect. Remarkably, these models are consistent with other complementary indicators of dark energy, such as luminosity-distance measurement from high redshift supernal and the census of massive clusters with redshift. They have also suggested that the upcoming CMB polarisation measurements from Planck could help resolve the origin of large angle power deficit in CMB temperature fluctuations. This work provides the first suggestion that nagging deviations from the standard LCDM cosmology can be interpreted and analysed as signatures of exotic nature of the dark sector in the universe. In collaboration with Arman Shafieloo, they have studied signatures in CMB power spectrum of marked variations in equation of state of dark energy that have been recently proposed based on fits to the luminosity-distance measurement of high redshift supernova.

Early universe from CMB

With former IUCAA student, Arman Shafieloo (currently, faculty at APCTP, Korea) and his post-doc Dhiraj Hazra, **Tarun Souradeep** has continued his research programme to assess the

impact on cosmological parameter estimation of allowing for a free form Primordial Power Spectrum (PPS). A few years back, Shafieloo and **Souradeep** had shown that meaningful estimation of cosmological parameters was possible even when the PPS was allowed full freedom to vary. In a recent publication, listed among the Planck external paper, they have revised and updated deconvolution scheme that allows identification of free form PPS that have very high likelihood to the measured CMB angular power spectrum. This allows sampling the function space of PPS, which would contribute most to a 'marginalization' over PPS degree of freedom. Another recent publication demonstrates that WMAP-9 data can be used to rule out a universe without cosmological constant at over 4σ, even when granted full freedom to the form of PPS. **Jayanti Prasad** has been guiding Asif Ahangar, a student of IUCAA associate, Manzoor Malik (Kashmir University) on a comprehensive study of the observational compatibility of various models of inflation with respect to the recent Planck data.

Cosmological parameter estimation

Santanu Dasa has developed an adaptive MCMC method, named, SCopE that allows significantly more rapid convergence than widely used MCMC algorithm called, CosmoMC. Conservative estimates give at least a factor of 2.5 reduction in computational effort for the standard 6 parameter cosmological model. **Das** and **Suvodip Mukherjee** have used SCopE to carry out a very interesting exercise that assesses the ramification of two cosmological measurements that are apparently at odds with the cosmological parameter limits provided in the first year Planck results in April 2013. These are the SDSS-BOSS measurement of neutrino mass of 0.26 eV and the BICEP-2 claim of detection of inflationary gravitational wave background at tensor-to-scalar ratio of 0.2. Figure shows the changes in the estimation of vital cosmological parameters implied by the SDSS and BICEP measurements.

Maximum entropy deconvolution of primordial power spectrum

It is well known that cosmic microwave background (CMB) temperature anisotropies and polarization can be used to probe the metric perturbations in the early universe. Presently, there exists no observational detection of tensor modes of primordial metric perturbations or of primordial non-Gaussianity. In such a scenario, the primordial power spectrum of scalar metric perturbations is the only correlation function of metric perturbations (presumably generated during inflation), whose effects can be directly probed through various observations. To explore the possibility of any deviations from the simplest picture of the era of cosmic inflation in the early universe, it thus becomes extremely important to uncover the amplitude and shape of this correlation sufficiently well. **Gaurav Goswami** and **Jayanti Prasad** have developed a method for reconstructing the primordial power spectrum of scalar metric perturbations using the Maximum Entropy Method (MEM) to solve the corresponding inverse problem. Using the WMAP-9 data, they have shown that there are no convincing reasons to believe that the primordial power spectrum of scalar metric perturbations has any significant features.

Cosmic Magnetic Fields

Resilience of helical fields to turbulent diffusion: Direct numerical simulations

The recent study of E. Blackman and **K. Subramanian** indicates that large scale helical magnetic fields are resilient to turbulent diffusion in the sense that helical fields stronger than a critical value, decay on slow (resistively mediated), rather than fast (turbulent) time scales. This gives more credence to potential fossil field origin models of the magnetic fields in stars, galaxies and compact objects. **P. Bhat**, Blackman and **Subramanian** have analyzed a suite of direct numerical simulations (DNS) of decaying large scale helical magnetic fields in the presence of non-helical turbulence to further study the physics of helical field decay. They have studied two separate cases: (1) The initial field is large enough to decay resistively, is tracked until the transitions to decay fast, and the critical large scale helical field at that transition is sought, (2) The case of the earlier work, wherein there is a critical initial helical field strength, below which the field

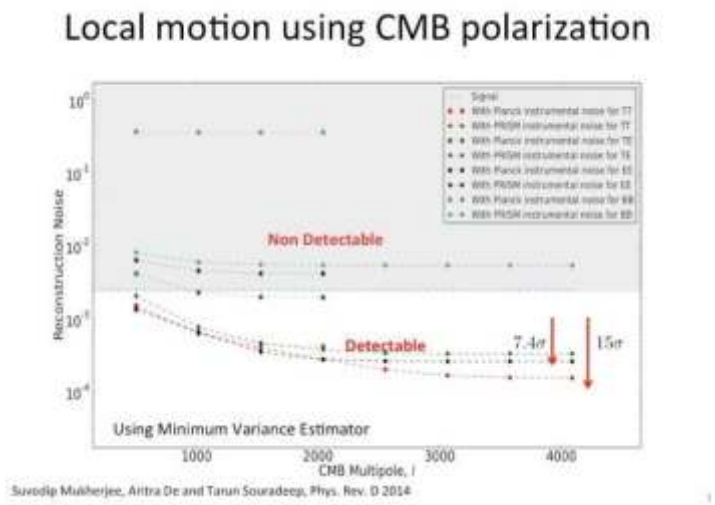

Figure 17: Prospects of measuring our local motion with respect to cosmic rest frame from all sky CMB polarisation measurements.

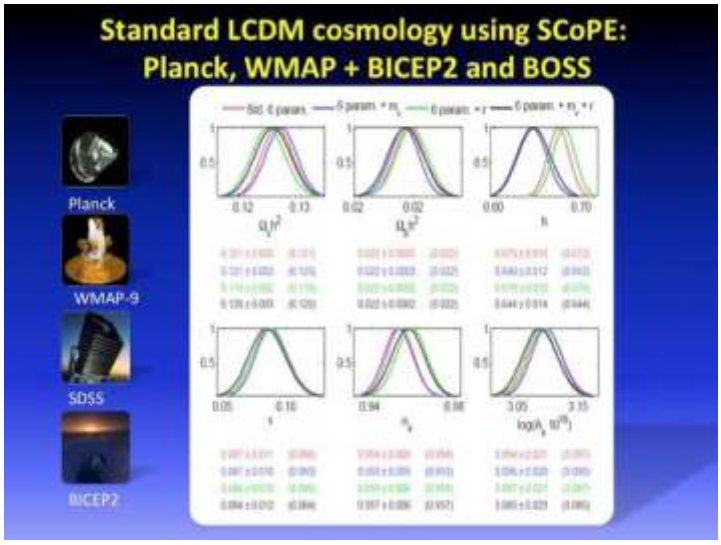

Figure 18: Cosmological parameter estimation using an adaptive MCM algorithm SCopE. The figure compares the cosmological parameter estimates with and without the imposition of SDSS-BOSS measurement of neutrino mass and claimed detection of inflationary gravitational wave background by BICEP-2.

undergoes fast decay right from the beginning. In case (1), both DNS and solutions of the two scale model, reveal that the transition energy E_{c1}, is independent of the scale of the turbulent forcing, within a small range of magnetic Reynolds numbers (RM). They have also found that the kinetic alpha is sub-dominant to magnetic alpha in the DNS, justifying an assumption in the two scale model. For case (2), they have shown exact solutions of two scale model in the ideal limit of the fully helical case, leading to the transition energy, $E_{c2} = (k_1/k_f)^2 M_{eq}$, where k_1 and k_f are the large scale and small turbulent forcing scale respectively and M_{eq} is the equipartition magnetic energy. The DNS in this case agree qualitatively with the two scale model but the RM currently achievable is too small to satisfy a condition $3/RM << (k_1/k_f)^2$, which is necessary to robustly reveal the transition.

Large-scale dynamo growth rates from numerical simulations and implications for mean-field theories

Understanding large-scale magnetic field growth in turbulent plasmas in the magnetohydrodynamic limit is a goal of magnetic dynamo theory. In particular, assessing how well large-scale helical field growth and saturation in simulations match those predicted by existing theories is important for progress. Using numerical simulations of isotropically forced turbulence without large-scale shear, K. Park, E. Blackman and **K. Subramanian** have focussed on several additional aspects of this comparison: (1) Leading mean-field dynamo theories which break the field into large and small scales predict that large-scale helical field growth rates are determined by the difference between kinetic helicity and current helicity, with no dependence on the non-helical energy in small-scale magnetic fields. Their simulations have shown that the growth rate of the large-scale field from fully helical forcing is indeed unaffected by the presence or absence of small-scale magnetic fields amplified in a precursor non-helical dynamo. However, because the precursor non-helical dynamo in our simulations produced fields that are strongly sub-equipartition with respect to the kinetic energy, they cannot yet rule out the potential influence of stronger non-helical small-scale fields. (2) They have identified two features in our simulations, which cannot be explained by the most minimalist versions of two-scale mean-field theory: (i) Fully helical small-scale forcing produces significant non-helical large-scale magnetic energy, and (ii) The saturation of the large-scale field growth is time delayed with respect to what minimalist theory predicts.

Magnetic arms generated by multiple interfering galactic spiral patterns

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. The non-axisymmetric galactic mean-field dynamo model of **Luke Chamandy**, et al. is generalized to allow for such multiple co-existing spiral patterns, 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 model parameters, but can become comparable to typically inferred values for certain (still realistic) parameters. The magnetic field is sometimes strongest in between the arms, unlike in standard models with a single pattern, where it is strongest within the 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. This work has been done by **Chamandy**, **K. Subramanian**, and A. Quillen.

Non-linear galactic dynamos: A toolbox

Luke Chamandy, A. Shukurov, **K. Subramanian** and K. Stoker have compared various 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 and an algebraic dynamo-quenching. The non-linear solutions are then compared with the marginal kinematic and asymptotic solutions. They have also discussed the accuracy of the no - z approximation. Although these tools are very different in the degree of approximation and hence complexity, they all lead to remarkably similar solutions for the mean magnetic field. In particular, they have shown that the algebraic quenching non-linearity can be obtained from a more physical dynamical 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. They have suggested improved no - z and algebraic 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.

Primordial magnetic field limits from the CMB trispectrum: Scalar modes and Planck constraints

Cosmic magnetic fields are observed to be coherent on large scales and could have a primordial origin. Non-Gaussian signals in the cosmic microwave background (CMB) are generated by primordial magnetic fields as the magnetic stresses, and temperature anisotropy they induce depend quadratically on the magnetic field. P. Trivedi, **K. Subramanian** and T. R. Seshadri have computed the CMB scalar trispectrum on large angular scales, for nearly scale-invariant magnetic fields, sourced via the Sachs-Wolfe effect. The trispectra induced by magnetic energy density and by magnetic scalar anisotropic stress are found to have typical magnitudes of approximately $10^{H\ R29}$ and $10^{H\ R19}$, respectively. The scalar anisotropic stress trispectrum is also calculated in the flat-sky approximation and yields a similar result. Observational limits on CMB non-Gaussianity from the Planck mission data allow us to set upper limits of $B_0\ I0.6$ nano Gauss on the present value of the primordial cosmic magnetic field. Considering the inflationary magnetic curvature, mode in the trispectrum can further tighten the magnetic field upper limit to $B_0\ I0.05$ nano Gauss. These sub-nano Gauss constraints from the magnetic trispectrum are the most stringent limits so far on the strength of primordial magnetic fields, on megaparsec scales, significantly better than the limits obtained from the CMB bispectrum and the CMB power spectrum.

Cosmological magnetogenesis from extra-dimensional Gauss-Bonnet gravity

Generation of primordial magnetic fields during inflation typically requires the breaking of conformal invariance of the electromagnetic action. This has been achieved naturally in a higher dimensional cosmological model with a Gauss-Bonnet term in the action by the work of K. Atmjeet, I. Pahwa, T. R. Seshadri and **K. Subramanian**. The evolution of the scale factor of the extra dimension (whose dynamics is influenced by the Gauss-Bonnet term) acts as the cause for the breaking of conformal invariance. Different cases have been investigated, each of which is characterized by the number of higher dimensions, the value of the Gauss-Bonnet parameter, and the cosmological constant. Many of the scenarios considered are highly constrained by the requirements that the cosmic evolution is stable, the normal dimensions expand, and there

is no back reaction due to growing electric fields. However, there do exist scenarios which satisfy the above requirements and are well suited for magnetogenesis. In particular, a scenario where the number of extra dimensions, D = 4 and the cosmological constant is non-zero, turns out to be the best suited for generating primordial magnetic fields. It is shown that for these values of parameters, a scale invariant magnetic field of the order of $10^{H\ R10}\ H\ R10^{H\ R9}$ G can be produced. Even in these most favourable scenarios, the higher dimensional space expands during inflation at the same rate as the normal dimension. Hence, if a mechanism could freeze the evolution of the higher dimension, this seems to be a viable mechanism to produce acceptable primordial magnetic fields.

A physical model for the redshift evolution of high-z Lyman Break Galaxies

C. Jose, R. Srianand and **K. Subramanian** have presented a semi-analytic galaxy formation model to understand the evolution of stellar mass - UV luminosity relations, stellar mass functions and specific star formation rate (sSFR) of Lyman Break Galaxies (LBGs) along with their UV luminosity functions in the redshift range $3 < z < 8$. They have used a physical model for star formation in galaxies, and the model parameters are calibrated by fitting the observed UV luminosity functions of LBGs. The fraction of baryons that gets converted into stars remains nearly constant for $z > 4$ but shows an increase for $z < 4$. However, the rate of converting baryons into stars do not evolve significantly in the redshift range $3 < z < 8$. Thus, dark matter halo build up in LCDM model is sufficient to explain the evolution of UV luminosity functions of LBGs in this redshift range. This model further successfully explains the stellar mass - UV luminosity correlations of LBGs. While this model predictions of stellar mass functions compare well with the inferred data from observations at the low mass end, they need to invoke the Eddington bias to fit the high mass end. They have found that at any given redshift the sSFR to be constant over the stellar mass range $5 \times 10^8 - 5 \times 10^9 M_*/M_\odot$ and the redshift evolution of sSFR is well approximated by $(1+z)^{2.4}$ for $3 < z < 8$, which is consistent with observations.

Active galaxies

Sibasish Laha, in collaboration with **Ajit Kembhavi**, **Gulab Dewangan**, Matteo Guainazzi (European Space Agency) and Susmita Chakravorty (Laboratorie de Astrophysique), France, has carried out a homogeneous analysis of the broadband 0.3 – 10 keV CCD resolution as well as of soft X-ray high-resolution grating spectra of a hard X-ray flux-limited sample of 26 Seyfert galaxies observed with XMM-Newton. Their goal is to characterise the warm absorber (WA) properties along the line-of-sight to the active nucleus. They have significantly detected WAs in 65% of the sample sources. Their results are consistent with WAs being present in at least half of the Seyfert galaxies in the nearby Universe, in agreement with previous estimates. They have found a gap in the distribution of the ionisation parameter in the range $0.5 < log < 1.5$, which has been interpreted as a thermally unstable region for WA clouds. This may indicate that the WA flow is probably constituted by a clumpy distribution of discrete clouds rather than a continuous medium. The distribution of the WA column densities 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 K emission lines are bonafide, and not artifacts 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 versus outflow velocity linear regression (0.12 ± 0.03) is inconsistent with the scaling laws predicted by radiation or magneto-hydrodynamic-driven winds. Their results suggest also that WA and Ultra Fast Outflows (UFOs) do not represent extreme manifestation of the same astrophysical system.

High Energy Astrophysics

Accretion onto neutron stars

Dipankar Bhattacharya, in collaboration with **Dipanjan Mukherjee** and Andrea Mignone (University of Torino, Italy) has undertaken detailed three-dimensional magneto-hydrodynamic simulations to investigate the stability of accretion mounds on neutron stars. The results confirm the spontaneous appearance of pressure-driven

instabilities that prevent the matter confined in the mound from ever growing to the maximum possible mass allowed in static equilibrium. This limits the gravitational wave luminosity that can be expected from such accreting neutron stars. The magnetic distortions caused by the accreted matter would leave their signature in the cyclotron absorption/emission features often observed from the accretion column. The time-varying, unstable flow would also impose temporal variations on the star's X-ray luminosity, which can be probed using high precision X-ray timing observations.

Timing analysis has been performed on the archival Rossi X-ray Timing Explorer data of an accreting neutron star system XTE J1701-407, revealing the presence of twin kilohertz quasi periodic oscillation (QPO) peaks separated by 385 Hz. This frequency difference is indicative of the spin frequency of the neutron star, and is among the highest values observed in such systems till date. The frequency of the upper QPO peak, a tracer of the location of the inner edge of the accretion disk, has been found to be as large as 1153 Hz, also among the highest recorded. This suggests that the accretion disk approaches the surface of the neutron star to within 5 km before the flow is magnetically channelled towards the star's poles. This work has been done by **Bhattacharya** in collaboration with Devraj Pawar (University of Mumbai) and a team led by Diego Altamirano (The University of Amsterdam).

Search for millisecond radio pulsars with the Giant Metrewave Radio Telescope at the locations of Fermi gamma ray sources has led to the discovery of PSR J 1544+4937, an exotic "Black Widow" system in which the electromagnetic and particulate radiation from the pulsar is in the process of vaporising its nearby companion. This energetic pulsar has a very short spin period of 2.16 milliseconds and an orbital period of 2.9 hours. This pulsar discovery has been made by **Bhattacharya**, in collaboration with Bhaswati Bhattacharyya, J. Roy and Y. Gupta (all from NCRA), and its multi-wavelength follow-up was carried out by an international team spread across several major observatories around the world.

CZTI calibration

Currently **Nilkanth Vagshette** has been working on ground-based calibration of Cadmium Zinc Telluride Imager (CZTI) detector. This imager is one among the four X-ray instruments on board the multi-wavelength astronomy satellite ASTROSAT. CZTI covers the hard X-ray band, with a broad energy response from 10 to 200 keV. CZT detector consist of four identical and independent quadrant (Q or FQ (flight quadrant)), namely FQ1, FQ2, FQ3 and FQ4 with each quadrant configured as a 4 x 4 matrix of 16 detector modules (64 detector modules in four quadrant), and each module is pixellated an array of 16 x 16, therefore, in total 16,384 (64 MOD $\times$ (16 pix $\times$ 16 pix)) pixels are used to fabricate the CZT detector.

The aim is to calibrate each pixel with greater accuracy. In the ground-based calibration, we have found a number of dead + noisy + bad pixels in each module. Approximately, we have found 1 - 3% pixels are dead + noisy + bad in each module. Apart from this, they have also produced the alpha-tag technique to calibrate the individual pixels in the detector. The alpha-tagging is important to understand the characteristics of the detectors and their variation with time and changing operating conditions in space.

In X-ray spectroscopic calibration, the aim is to find the gain-offset values for each pixel, i.e., linearity. For this, data have been obtained by shining various four radioactive sources (namely Am, Ba, Cd and Co shown in Figure 19) on the quadrant at various temperatures in the range 05 - 25 deg C. They have used these data to estimate the stability of detectors, identify the best pixels, calculate their gains and offsets, energy calibration (i.e,. find the resolution at various temperature) and test the temperature dependence properties. The ADC channel to energy (keV) conversion is given by Energy = Channels $\times$ Gain + Offset
gain, and offset were measured at different temperature for each pixel. The energy Vs resolution plot of various calibrating sources is shown in Figure 20.

Galaxy and Interstellar Medium

Interstellar dust models towards some IUE stars

Nisha Katyal, **Ranjan Gupta** and D.B. Vaidya have studied the extinction properties of composite

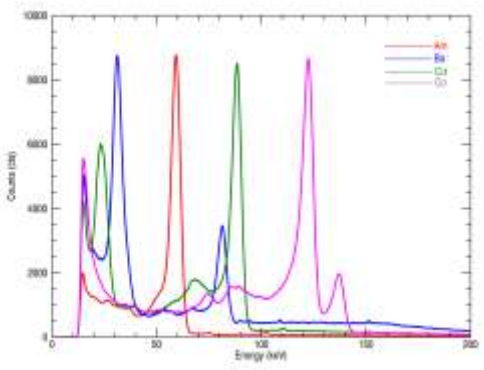

Figure 19: The 1keV smoothed spectrum measured at 05^0C temperature.

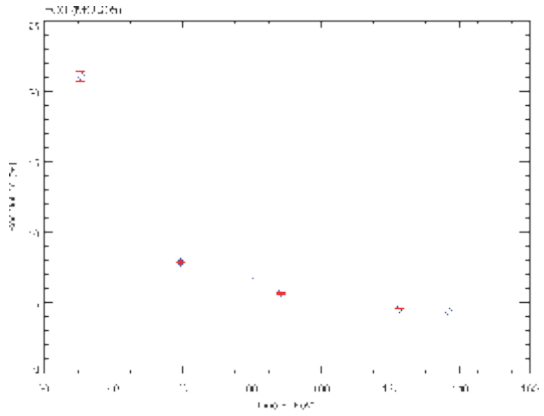

Figure 20: The measured line energy Vs their corresponding resolution (at 05^0C) in percentage.

dust grains, consisting of host silicate spheroids and graphite as inclusions, using discrete dipole approximation (DDA). They have calculated the extinction cross sections of the composite grains in the ultraviolet spectral region, $1200 - 3200$Å, and study the variation in extinction as a function of volume fraction of the inclusions. Further, they have compared the model extinction curves with the observed interstellar extinction curves obtained from the data given by the International Ultraviolet Explorer (IUE) satellite. The results for the composite grains show a distinct variation in the extinction efficiencies with the variation in the volume fraction of the inclusions. In particular, it is found that the wavelength of peak absorption at $2175\mathring{A}$ shifts towards the longer wavelength with the variation in the volume fraction of inclusions. It has been found that the composite grain models with the axial ratios, viz. 1.33 and 2.0 fit the observed extinction reasonably well with a grain size distribution, a = 0.005 - 0.250 μm. Moreover, the results on the composite grains clearly indicate that the inhomogeneity in the grain structure, composition, and the surrounding media modify the extinction properties of the grains.

The Figure 21 shows the main results of this analysis where the best fit dust models have been compared with the observed extinction curves at various dust environments in our galaxy.

Dust properties from GALEX observations of a UV halo around Spica

GALEX has detected ultraviolet halos extending as far as 5^0 around four bright stars (Murthy and Henry, 2011). These halos are produced by scattering of starlight by dust grains in thin foreground clouds that are not physically associated with the star. Assuming a simple model consisting of a single layer of dust in front of the star, Murthy and Henry (2011) have been able to model these halo intensities and constrain the value of the phase function asymmetry factor g of the scattering grains in the FUV and NUV. However, due to the uncertainty in the dust geometry they could not constrain the albedo. In this work P. Shalima, J. Murthy, and **Ranjan Gupta** have tried to constrain the optical constants and dust geometry by modeling the UV halo of Spica. Since the halo emission is not symmetric, they

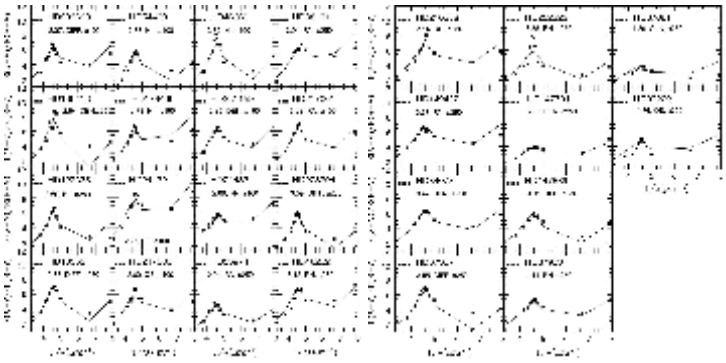

Figure 21: Comparison of the observed interstellar extinction curves with the best fit composite grain model extinction curves (generated using DDA) in the wavelength range 3.17 - 7.87 μm^{-1}(3200 − 1200Å). The observed Rv, environment type, and the best fit grain size distribution for the sample are shown.

have modeled the Northern and Southern parts of the halo separately. To the North of Spica, the bestfit albedo is 0.26±0.1 and g is 0.58±0.11 in the FUV at the 90% confidence level. The corresponding limits on the distance and optical depth (τ) of the dust sheet is 3.65±1.05 pc and 0.047±0.006 respectively. However, owing to a complicated dust distribution to the South of Spica, they have been unable to uniquely constrain the dust parameters in that region. Nevertheless, by assuming the optical constants of the Northern region and a denser medium, it has been able to constrain the distance of the dust to 9.5±1.5 pc and the corresponding τ to 0.04±0.01.

The Figures 22 and 23 show the region of interest from the GALEX sky image and the main result of this work where the model FUV intensity and its angular dependence are depicted.

Imaging polarimetry of the rotating Bok globule CB67

The following work has been carried out under an Indo-Russian exchange programme with Assam University, Silchar and IUCAA on the Indian side and St. Petersburg University, on the Russian side. by M.S. Prokopjeva, A.K. Sen, V.B. Il'in, N.V. Voshchinnikov and **Ranjan Gupta**.

Polarimetric observations of about 50 stars located in a close vicinity of the Bok globule CB67, having significantly non-spherical shape and rapid rotation have been performed. The data obtained are compared with the available observations of this globule at radio and submillimetre wavelengths as well as some theoretical calculations. It has been found that the elongation and the rotation moment of CB67 are oriented rather perpendicular to the magnetic fields, which are unusual for Bok globules and is difficult to be explained from the theoretical point of view.

The Figures 24, 25 and 26 show the polarization measurements carried out using IGO and OHP telescopes.

Dust coma of comet C/2009 P1 (Garradd) by imaging polarimetry

The following research was carried out under an INDO-FRENCH CEFIPRA exchange project with Assam University, Silchar and IUCAA, on Indian side and University of Paris Sud, Paris and UPMC, LATMOS, Paris on the French side.

E. Hadamcik, A.K. Sen, A.C. Levasseur-Regourd, S. Roy Choudhury, J. Lasue, **Ranjan Gupta** and R. Botet have observed Comet C/2009 P1 (Garradd) by imaging polarimetry for nearly 5 months from October 2011 to March 2012, over an intermediate phase angle range (28 - 35^0) Two months before perihelion and one month after, dust particles seem to be ejected all around the opto-centre and jets extend to distances greater than 40,000 km. An increase of activity has been noticed in intensity and polarization after perihelion. Two and three months after perihelion, the jets are mainly towards the solar direction with an extension of more than 20,000 km projected on

Figure 22: GALEX FUV image of the diffuse sky with the halo around Spica shown within the square in the Northern galactic hemisphere.

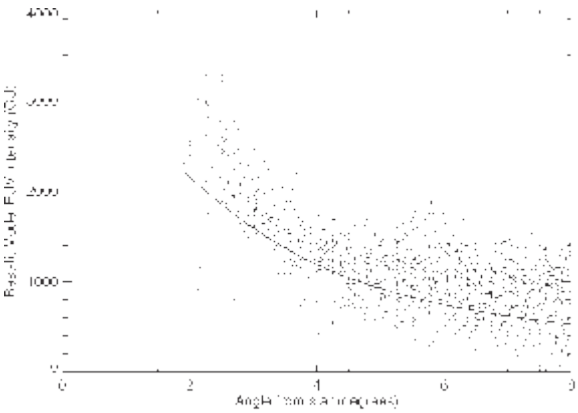

Figure 23: Angular dependence of the observed and model FUV intensity of the halo towards the South of Spica.

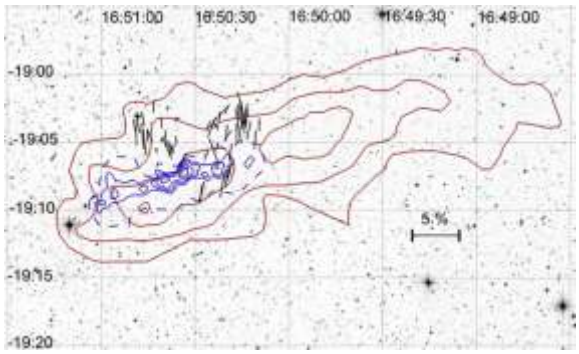

Figure 24: Polarization of stars in the region of CB67. The dotted lines show emission in the ^{13}CO line, and the solid lines, emission at $\lambda = 850\mu m$. The dashed line confines the field observed in the submillimetre range.

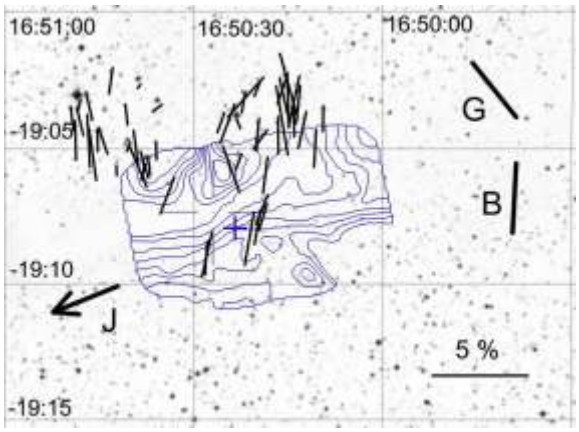

Figure 25: Rotation of CB67. The solid lines are contours of the mean radial velocity. Location of the centre of motion (the peak of ^{13}CO integrated intensity) is given by the cross. The projected angular momentum **J**, the Galactic plane direction **G**, and the average magnetic field direction $\mathbf{B}_\perp$ are presented by the corresponding vectors. Polarization of the stars observed is also given.

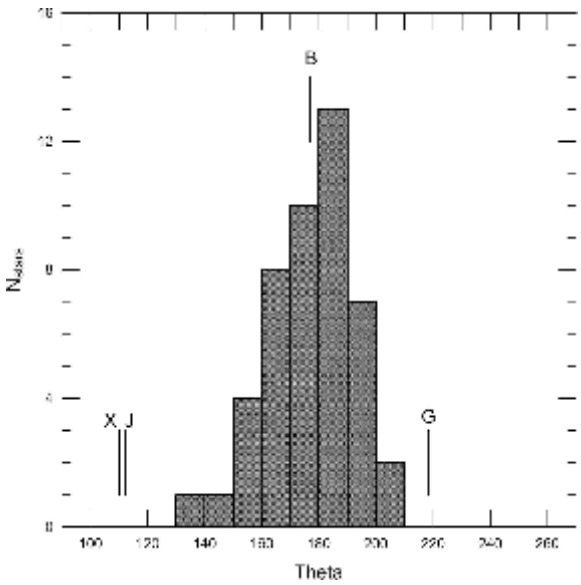

Figure 26: The distribution of all stars observed over θ. The labels show the position angles of the largest extension in visual X, the angular moment **J**, the Galactic plane **G**, and the mean magnetic field **B**.

the sky. The values of the aperture polarization are comparable to those of other comets. On the polarization maps in October 2011 and January 2012, the higher polarization zones extend in large regions perpendicularly to the solar direction where jets are also observed. In February and March 2012, the polarization in the jets is larger in the solar direction than in the surrounding coma. By its activity visible on intensity images and polarization maps at large distances from the nucleus, comet Garradd probably belongs to the high-P_{max} class of comets.

Figures 27, 28 and 29 show the comet images and measured polarization values.

Solar Physics

Doppler shifts in active region moss

One of the most puzzling problems for astrophysicists over the last few decades is determining how the solar corona is heated to millions of degrees. There have been numerous developments toward understanding this problem. Solar telescopes have provided excellent observations of the Sun's atmosphere that has helped to better define the characteristics of coronal plasma. Additionally, there have been significant improvements in theoretical modeling of coronal structures. However, the ultimate solution to coronal heating problem remains elusive. It has been known, since the Skylab era, that a significant amount of radiation emitted from solar corona is from loop structures. This is particularly evident in active regions. More recent observations reveal that active regions comprise of different kind of loop structures. These loops are now broadly classified as fan loops, warm loops, and hot core loops. In addition, it has been found that there is a significant amount of radiation emitted from the diffuse background/foreground. It is likely that we are not resolving the fundamental elemental flux tubes, or strands, in the solar corona; hence, the observed loops may be formed of many sub-resolution strands as suggested by filling factor measurements using Hinode/Extreme-ultraviolet Imaging Spectrometer (EIS). The frequency of the heating on the (potentially sub-resolution) strands is one of the fundamental discriminators of different heating mechanisms.

It is believed (though there is no consensus) that warm loops are heated by low-frequency nanoflares, a so-called short nanoflare storm. The heating of hot core loops, however, is a matter of strong debate. Observations have provided evidence for both low-frequency and high-frequency (quasi-steady) nanoflare heating. Because the coronal loops are likely not resolved, the physical properties of the plasma must be used to distinguish between low- and high-frequency heating. Furthermore, due to the inherent fuzziness of the hot loops, it becomes even more cumbersome to resolve a loop-like structure in the core of the active regions. Therefore, we have to rely heavily on the techniques that do not demand the fundamental structures to be resolved. These diagnostics include emission measure and Doppler shift techniques.

Durgesh Tripathi, along with his collaborators have studied Doppler shift in moss regions, which are the footprints of the hot core loops by combining the observations from Solar Ultraviolet Measurements of Emitted Radiation (SUMER) on Solar and Heliospheric Observatory and Transition Region and Coronal Explorer (TRACE). The observations from SUMER allowed us to measure the wavelength scale of the observations with an uncertainty in the absolute velocity of less than 3.5 kms^{-1}. Figures 30 shows image of an active region observed by TRACE (top row, left panel), image obtained in Ne VIII spectral line (top row, middle panel) and Doppler map of the active region (top row, right panel). The bottom panel shows the distribution of velocities obtained in three different spectral lines, namely Ne VIII (770 $\circ A$), C IV (1548 A) and C IV (1550 A). The distribution shows a clear signature of down-flowing plasma in moss regions, with increasing amplitude with decreasing temperature. This provides unambiguous evidence of low frequency nano-flare heating in active regions cores.

Origin of macrospicules and jet in polar corona by small scale kinked flux tube

Macrospicules are giant spicules, mostly observed in polar coronal holes, reaching heights between 7 and 45 Mm above the solar limb with lifetimes of 345 minutes. A number of mechanisms have been proposed for the formation of such plasma

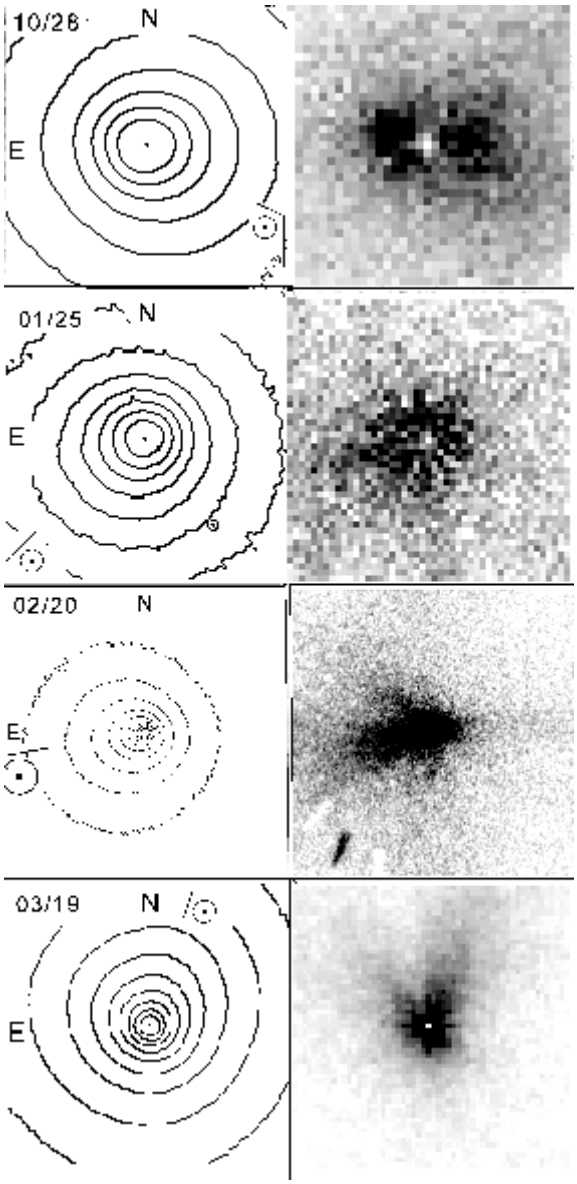

Figure 27: Shows the intensity images for October, January, February, and March. Left column: Isophotes with the solar direction indicated by a line with image. Right column: Images of intensity treated by a rotational gradient method (in negative). Fields: 45,000 × 45,000 km.

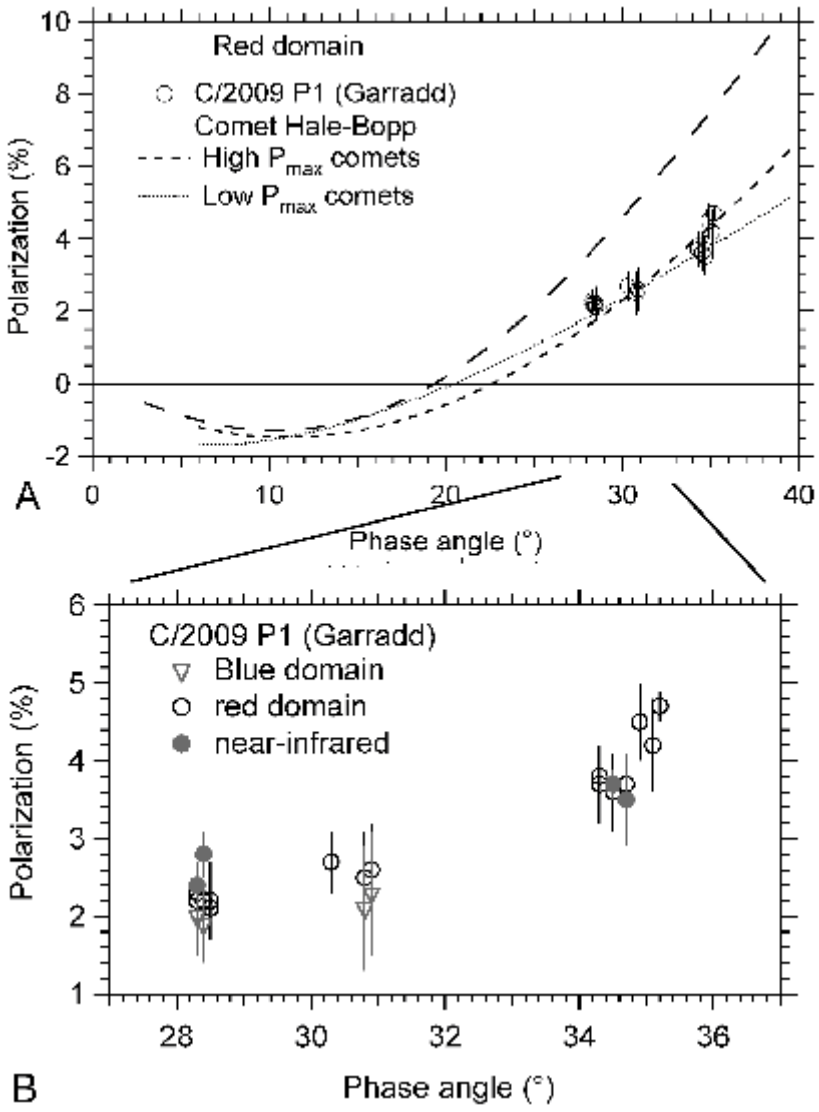

Figure 28: Polarization curves. Above: In the red wavelength domain with comparison to other comets. Below: Comparison between data obtained at different wavelengths.

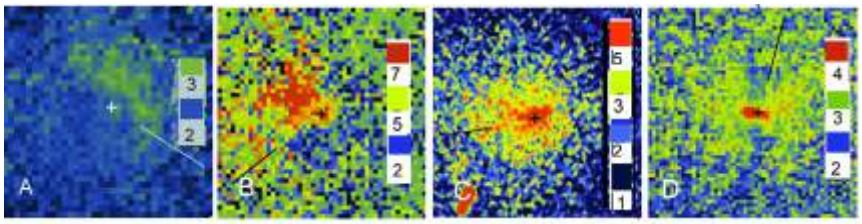

Figure 29: Polarization maps: (A) 2011 October (R_{OHP} filter), (B) 2012 January (RC filter), (C) 2012 February (R_{IGO} filter), (D) 2012 March (I_{OHP} filter) observations. To improve the display, a Gaussian filter was applied. Opto-centre +, Straight line: solar direction. Colour or gray scales in per cent.

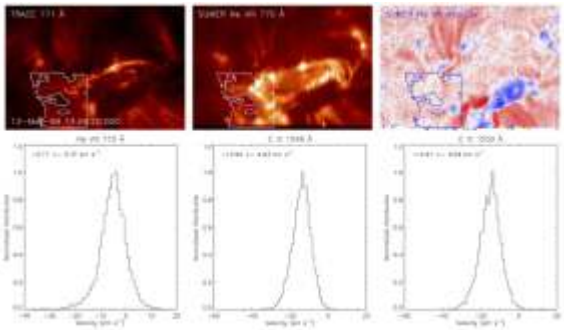

Figure 30: Top panel: Intensity (TRACE 171 A and SUMER 770 A) and Doppler map of the active region showing moss regions. Bottom panel: Distribution of velocities in the moss pixels shown by contours. Note that the negative velocity means down-flows and positive means up-flows.

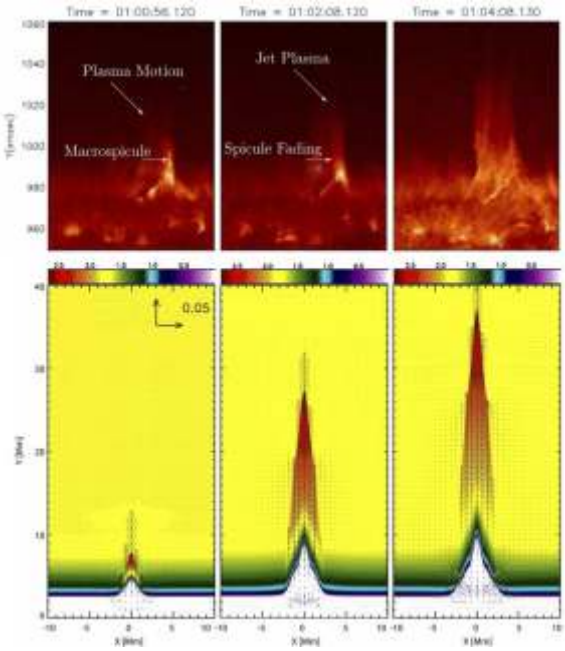

Figure 31: Top panel: Observation of a kinking flux tube and formation of a macrospicule as recorded by SDO/AIA. Bottom panel: Simulation of formation of a macrospicules by reconnection generated macrospicule.

ejecta, e.g., gas pressure pulse and velocity pulse. Shibata (1982) has suggested that if reconnection takes place in the upper chromosphere/lower corona (lower chromosphere/photosphere), the macrospicule can be triggered due to magnetic reconnection (the evolution of slow shocks). Alternative mechanisms have also been reported for the formation of such plasma ejecta.

Durgesh Tripathi along with his collaborators have observed a smallscale flux tube that underwent kinking and triggered a macrospicule, and a jet on 2010 November 11 in the North polar corona (top row of Figure 31). The small-scale flux tube emerged well before the triggering of the macrospicule and as time progresses the two opposite halves of this omega-shaped flux tube bent transversely and approach each other. After 2 minutes, the two approaching halves of the kinked flux tube touched each other and an internal reconnection as well as an energy release took place at the adjoining location and a macrospicule was launched, which reached up to a height of 12 Mm. Plasma began to move horizontally as well as vertically upward along with the onset of the macrospicule and thereafter converted into a largescale jet in which the core denser plasma reached up to 40 Mm in the solar atmosphere with a projected speed of 95 kms^{-1}. The fainter and decelerating plasma chunks of this jet were also seen up to 60 Mm. They have also performed a two-dimensional numerical simulation by considering the VAL-C initial atmospheric conditions to understand the physical scenario of the observed macrospicule and associated jet. The simulation results (bottom row of Figure 31) show that reconnection-generated velocity pulse in the lower solar atmosphere steepens into slow shock, and the cool plasma is driven behind it in the form of macrospicule. The horizontal surface waves also appeared with shock fronts at different heights, which most likely drove and spread the largescale jet associated with the macrospicule.

SDO/AIA observations of a partially erupting prominence

Prominence eruptions are one of the best proxies for coronal mass ejections (CMEs). Therefore, understanding the initiation and evolution of the erupting prominences provides a crucial

physical understanding of the dynamical processes involved in CME initiation and evolution, with broader implications for space weather and geo-space climate. Prominence eruptions show a range of observational characteristics including complete eruption, partial eruption, and failed or sympathetic eruption. Partial eruption of prominences is a relatively new phenomenon, which has been first described by Gilbert et al. (2000). They have been observed in the form of downflows from the erupting prominences. It has been found that a majority of the erupting prominences observed with the H coronagraph located at the Mauna Loa Solar Observatory (MLSO) have been associated with downflows. This has led to a hypothesis that during the process of eruption, the prominence breaks into two parts via internal magnetic reconnection taking place at X-type neutral point. Depending on the location of the internal magnetic reconnection, the prominence would show a complete, partial, or failed eruption.

Durgesh Tripathi with his collaborators have reported an observation of a partially erupting prominence and its associated dynamical plasma processes based on observations recorded by the Atmospheric Imaging Assembly (AIA) on board the Solar Dynamics Observatory. The prominence first went through a slow rise (SR) phase followed by a fast rise (FR) phase. The SR phase began after a couple of small brightenings were seen towards the foot points. When the prominence had transitioned from SR to FR, it had already become kinked. The prominence showed strong brightening at the central kink location during the start of FR (see Figure 32). They have interpreted this as an internal magnetic reconnection occurring at a vertical current sheet forming between the two legs of the erupting prominence (flux rope). The brightening at the central kink location was seen in all EUV channels of AIA. The contributions of differential emission at higher temperatures was larger compared to that for typical coronal temperatures supporting a reconnection scenario at the central kink location. The plasma above the brightening location was ejected as a hot plasmoid-like structure embedded in a coronal mass ejection, and those below the brightening move down in the form of blobs moving toward the Sun's surface. The unique time resolution of the AIA allowed these eruptive aspects, including SR-to-FR, kinking, central current sheet formation, plasmoid-like eruption, and filament "splitting," to be observed in a single event, providing strong and comprehensive evidence in favour of the model of partially erupting flux ropes.

Asymmetries in coronal spectral lines and emission measure distribution

It has previously been argued that (1) spicules do not provide enough pre-heated plasma to fill the corona, and (2) even if they did, additional heating would be required to keep the plasma hot as it expands upward. **Durgesh Tripathi** and Jame Klimchuk have addressed whether spicules play an important role by injecting plasma at cooler temperatures ($< 2MK$), which then gets heated to coronal values at higher altitudes. They have measured redblue asymmetries in line profiles formed over a wide range of temperatures in the bright moss areas of two active regions and derived emission measure distributions from the excess wing emission. It has been found that the asymmetries and emission measures are small, and concluded that spicules did not inject an important (dominant) mass flux into the cores of active regions at temperatures $>$ 0.6 MK ($logT > 5.8$). These conclusions apply not only to spicules but also to any process that suddenly heats and accelerates chromospheric plasma (e.g., a chromospheric nanoflare). The traditional picture of coronal heating and chromospheric evaporation appears to remain the most likely explanation of the active region corona.

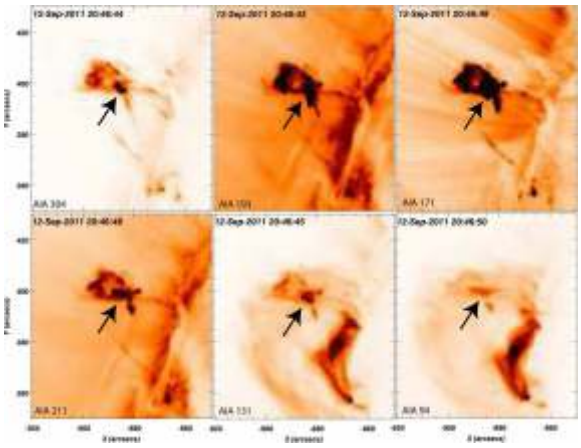

Figure 32: Sequence of SDO/AIA images recorded with all of the EUV channels showing the brightening at the location of the kinked flux rope. The arrows mark the location of possible magnetic reconnection and heating.

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104. P. Gandhi, Y. Terashima, S. Yamada, R. F. Mushotzky, Y. Ueda, W. H. Baumgartner, D. M. Alexander, J. Malzac, **K. Vaghmare,** T. Takahashi, and C. Done (2013) *Reflection-dominated nuclear X-ray emission in the early-type galaxy ESO 565-G019*, ApJ, **773**, Issue 1.

105. **M. Vivek**, **R. Srianand,** P. Petitjean, V. Mohan, A. Mahabal, and S. Samui (2014) *Variability in low ionization broad absorption line outflows*, MNRAS, **440**, 799.

(b) Proceedings

1. Sapna Sharma, Moti R. Dugair, **D. Bhattacharya,** and S. N. A. Jaaffrey (2013) *Timing and spectral studies of Gamma-ray burst 111228A detected with SWIFT-BAT,* ASI Conf. Ser., **9**, 118.

2. **S. Das** and **T. Souradeep** (2014) *Dipole leakage and low CMB multipoles*, Proc. of ICGC 2011, Goa, J. Phys.: Conf. Ser., **484**, 012029.

3. **N. Gupta, R. Srianand**, P. Petitjean, P. Noterdaeme, and E. Momjian (2014) *Galaxies in HI 21-cm absorption at z < 3.5BASI*, The Metrewavelength Sky Conference, NCRA, Pune.

4. R. Lindner, A. J. Baker, J. P. Hughes, N. Battaglia, **N. Gupta**, K. Knowles, T. Marriage, F. Menanteau, K. Moodley, E. D. Reese, and **R. Srianand** (2014) The radio relics and halo of El Gordo, a Massive cluster at z = 0.870, AAS, 22310606.

5. V. Jithesh, A. U. Preetha, **R. Misra**, **S. Ravindranath**, **Gulab C. Dewangan**, C. D. Ravikumar, K. Jeena, and B. R. S. Babu (2013) *Multi-wavelength studies of ultra luminous X-ray sources in NGC1427*, Astronomical Society of India Conf. Ser., **9**, 127.

6. **D. Mukherjee**, **D. Bhattacharya**, and A. Mignone (2014) *Magnetic field structure in accretion columns on HMXB and effects on CRSF*, Conference on physics at the magnetospheric boundary in compact objects, EPJ web of conf., **64**, 02004.

7. **N. Pant**, **A. Rotti**, and **T. Souradeep** (2014) *Statistics of statistical anisotropy measures*, Proc. of ICGC 2011, Goa, J. Phys.: Conf. Ser., **484,** 012046.

8. **Jayanti Prasad,** and **Tarun Souradeep** (2014) Cosmological parameter estimation using Particle Swarm Optimization, Proc. of ICGC 2011, Goa, J. Phys.: Conf. Ser., **484,** 012047

9. Abhik Ghosh, **Jayanti Prasad,** Somnath Bhardwaj, Sk. Said Ali, and Jayaram Chengalur (2014) *Characterizing the diffuse foreground for red-shifted 21 cm HI signal GMRT 150 MHz observations*, Proc.

Of ICGC 2011, Goa, J. Phys.: Conf. Ser., **484**, 012032

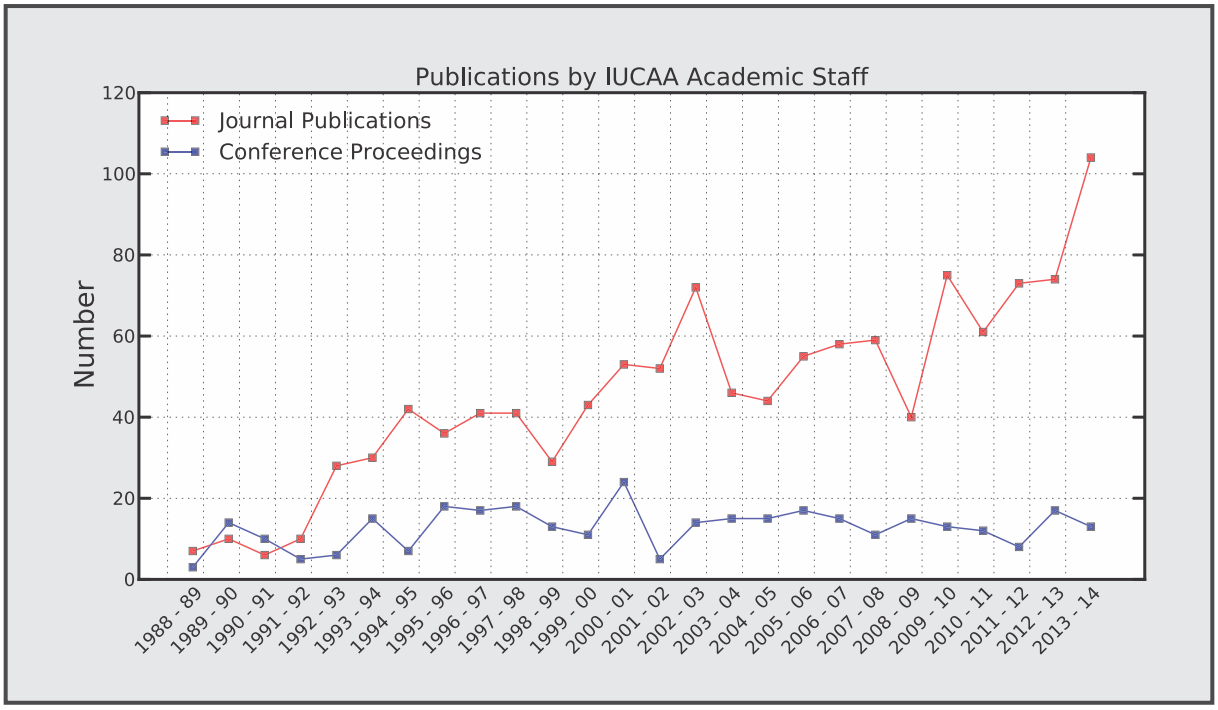
10. Eswaraiah C.,..., **A. N. Ramaprakash,** … et. al. (2013) *LDN 1570 BV (RI) c polarisation and photometry,* VizieR On-line Data Catalog: J/A+A/556/A65.

11. Baranec C.,…, **A. N. Ramaprakash,** … et. al (2013) *Rise of the machines: First year operations of the Robo-AO visible-light laser-adaptive optics instrument*, Proc. AMOS 2013 Technical Conf., (arXiv:1210.0532, arXiv: 1302.3224)

12. Baranec C.,…, **A. N. Ramaprakash,** … et. al (2013) *Robotic visible-light laser adaptive optics*, Proc. of the Third AO4ELT Conference.

13. A. Hillier, R. Hillier, and **D. Tripathi** (2014) *Determination of prominence plasma beta from the dynamics of rising plumes*, Proc. of the International Astronomical Union, IAU Symposium on Nature of Prominences and their role in Space Weather. Edited by Brigitte Schmieder, Jean-Marie Malherbe and S.T Wu, **300**, 94.

14. **Shruti Tripathi**, **R. Misra**, and **Gulab C. Dewangan** (2013) *Suzaku and XMM-Newton view of Mrk 110 and Ark 564*, Astronomical Society of India Conf. Ser., **9**, 133.



PEDAGOGICAL

(a) IUCAA-NCRA Graduate School

Dipankar Bhattacharya : Introduction to Astronomy and Astrophysics I (14 lectures) (August – October 2013)

Sukanta Bose : Quantum and Statistical Mechanics I (14 lectures) (August – October 2013)

S. V. Dhurandhar : Methods of Mathematical Physics I (14 lectures) (October – December 2013)

Ajit Kembhavi : Introduction to Astronomy and Astrophysics II (14 lectures) (October – December 2013)

Ranjeev Misra : Electrodynamics and Radiative Processes I (14 lectures) (August - October 2013)

T. Padmanabhan : Methods of Mathematical Physics II (14 lectures) (August – October 2013)

A. N. Ramaprakash : Astronomical Techniques I (14 lectures) (January – February 2014)

Kandaswamy Subramanian : Electrodynamics and Radiative Processes II (14 lectures) (October – December 2013)

(b) University of Pune, M.Sc. (Physics)

Sanjit Mitra : *General Relativity (Astronomy and Astrophysics II)*

(c) Supervision of Projects

Dipankar Bhattacharya

Amit Seta (Academy SRFP), Magnetic fields from turbulence (Joint supervision with **K. Subramanian**).

Vishakha Gupta (BITS, PS-1), Coded mask imaging with ASTROSAT CZTI.

A. Gopakumar (IUCAA, VSP), Timing properties of Hercules X-1.

Gulab Dewangan

Savithri Ezhikkode, DST project on Broadband spectral investigation of active galactic nuclei.

Pramod Pawar (Ph. D. student at SRTM University, Nanded), Optical-X-ray variability of AGN.

Mahadev Pandge (Ph. D. student at SRTM University, Nanded), FR-I radio galaxy CTD 86.

Ajit Kembhavi

Navami Venugopal (IUCAA, VSP), Warm absorbers.

Parita Mehta, Study of galaxy structure – Isophote fitting technique .

Sanjit Mitra

Bhooshan Gadre, for his graduate school project

Saurabh Kumar, a Junior Research Fellow under my SERB Fast Track grant

Shilpa Kashtha, IUCAA, VSP and her M. Sc. project at Visva-Bharati University

Sonu Tabitha Paulson, Madras University for her IAS summer project

Swarali Karkhanis, BITS-Pilani, Goa Campus for her summer project

Durgesh Tripathi

Sameer Salunkhe, M. Sc. project, Department of Physics, Pune University
Sherry Chhabra, M. Sc. project, Department of Physics, Ferguson College, Pune

J.V. Narlikar

Summer School Students' Programme, Foucault Pendulum

K. Subramanian

Amit Seta (IUCAA, VSP)

B. Hareesh Gautham, BITS- Pilani, Practice School project.

Tarun Souradeep

Saikat Chatterjee, M. Sc. project, Presidency University, Kolkata

(d) Co-Supervision of Ph. D. Thesis (other than IUCAA)

Tarun Souradeep
Cosmological Parameter Estimation: New Methodologies for Better Inference
Amir Aghamousa, University of Pune

Constraining Statistical Anisotropy with Observations
Nidhi Joshi, Jamia Millia Islamia, New Delhi

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

Dipankar Bhattacharya
Accretion Induced Evolution of Neutron Star Magnetic Fields
Sandeep Kumar

T. Padmanabhan
Gravitational Dynamics and Thermodynamics of Horizons
Sanved Kolekar

R. Srianand
Exploring the High Redshift Universe using Quasar Spectroscopy
Hadi Rahmani Bayegi

Physics of the IGM and Evolution of the High Redshift Universe
Sowgat Muzahid

TALKS

(a) Seminars, Colloquia and Lectures

Joydeep Bagchi

Galaxy Groups and Clusters (2 lectures), for the Vacation Students Programme /Refresher Course in Astronomy and Astrophysics for College and University Teachers, IUCAA, May 2013.

Dipankar Bhattacharya

Fundamentals of Astronomy, Astronomy Workshop for College Teachers, Fergusson College, Pune, July 3, 2013.

ASTROSAT Data Flow: A Garuda use case, Garuda Grid workshop, CDAC, Bangalore, July 26, 2013 (via Skype).

High Energy Radiation Processes near Accreting Black Holes, Workshop on Accretion on to Black Holes, Goa, September 07, 2013.

The Role of Big Data in Astronomy and Astrophysics, Scientific Advisory Committee meeting to the Cabinet, New Delhi, October 22, 2013.

Big Data in Astronomy: The Citizen Science Initiative, DST-INSPIRE Workshop, Miranda House, New Delhi, December 17, 2013.

Gravitational Radiation from Accreting Neutron Stars and the Role of the ASTROSAT Mission, Gravitational Wave Physics and Astronomy Workshop, IUCAA, Pune, December 18, 2013.

Long Radio Follow-up of GRB030329 Afterglow, Regional Conference in Radio Science, Symbiosis University, Pune, January 03, 2014.

An Overview of ASTROSAT, MIT-IUCAA Workshop on X-ray Studies of Transient Astronomical Events, IUCAA, Pune, January 14, 2014.

Big Data in Astronomy: The Citizen Science Initiative, Frontiers in Astrophysics, Fergusson College, Pune, January 21, 2014.

Transients with ASTROSAT, Workshop on Transient Astronomy with Small Telescopes, IUCAA, Pune, January 31, 2014.

Sukanta Bose

Compact Binary Coalescences as Progenitors of Short Hard GRBs: What can Gravitational Wave Searches tell us?, International Meeting on Transients and Timing, IUCAA, Pune, March 4-8, 2013.

Compact Binary Coalescence: Computational Challenges, Astronomy with the Global Gravitational-Wave Detector Network Meeting, Cardiff, UK, February 19-21, 2013.

Status Update on LIGO-India, Conference on Gravitational Waves: New Frontier, Research Park, Seoul National University, Korea, January 16 – 18, 2013.

Gravitational Waves (2 lectures), Refresher Course in Astronomy and Astrophysics for College and University teachers and Vacation Students' Programme, IUCAA, Pune, June 3 - 4, 2013.

Preparations for LIGO India, *Beijing* Gravitational Wave Workshop, Tsinghua University, July 1, 2013.

Preparing for Gravitational Wave Observations in the Advanced Detector Era*, Field Theoretic Aspects of Gravity (FTAG), IIT Gandhinagar, September 5 – 8, 2013.*

Spin-Aligned Versus Non-spinning Template Banks in Searches for Spin-Aligned Compact Binary Coalescence Sources, Albert Einstein Institute, Hannover, January 23, 2014.

Physics and Astrophysics with Networks of Second-Generation Gravitational Wave Detectors, ICTS / IISc, Bangalore, July 5, 2013.

What can Physics and Astrophysics Detectors, Like LIGO-India Teach us?, Calcutta University, Kolkata, October 18, 2013.

Preparing for the First Gravitational Wave Discoveries, Radboud University, Nijmegen, January 21, 2014.

Seeing and Hearing Gravitational Wave Sources, St Xaviers College, Kolkata, March 7, 2014.

Preparing for the First Gravitational Wave Discoveries, Presidency University, Kolkata, March 5, 2014.

Naresh Dadhich

Gravity (2 lectures), Refresher Course in Astronomy and Astrophysics for College and University teachers and Vacation Students' Programme, IUCAA, Pune, May 16 and 17, 2013.

Pure Lovelock Gravity, Field Theoretic Aspects of Gravity (FTAG) Meeting, Indian Institute of Technology Gandhinagar, September 6, 2013.

Why Einstein (Had I Been Born in 1844!)? Department of Physics, Indian Institute of Science, Bangalore, September 27, 2013.

On Pure Lovelock Gravity, Centro de Estudios Cientificos, Chile, December 4, 2013.

On Pure Lovelock Gravity, Department of Physics, University Of Andres Bello, Chile, December 9, 2013.

On Pure Lovelock Gravity, Institute of Physics, Pontific Catholic University of Valparaiso, Chile, December 18, 2013.

Relativity for Everyone, Department of Physics, Banaras Hindu University, Varanasi, February 2014.

Gravity in Higher Dimensions, Department of Mathematics, University of KwaZulu-Natal, South Africa, March 20, 2014.

Gulab Dewangan

Relativistically Blurred X-ray Reflection and Complex Absorption in AGN, NCRA, November 29, 2013.

X-raying Accretion Disk and Corona, Conference on Accretion onto Black Holes, Goa, September 5-7, 2013.

X-raying the Central Engines of Active Galaxies, High Energy Emission Meeting from AGN, University of Kashmir, Srinagar, October 7-9, 2013.

Broadband X-ray Spectral Variability of AGN: Complex Absorption or Intrinsic Variations?, International Conference on the Restless Nature of AGNs: Variability as a Probe of the Central Engine, Naples, Italy, May 20-23, 2013.

Central Engines of Radio-Quiet AGNs, Workshop on Radio Studies of Galaxies and Galaxy Systems, IUCAA, March 4-6, 2014.

Ranjan Gupta

Large Telescopes and Career Opportunities in Astronomy, National Conference on Space for Students, Tagore Theatre, Chandigarh, April 4-5, 2013.

Astronomical Spectroscopy and Careers in Astronomy, Introductory Astronomy Workshop, Rajasthan University, Jaipur, September 2-4, 2013.

Tools to Study Light Scattering Phenomena, Light Scattering Techniques and Application to Astronomy and other areas, S. N. Bose National Centre for Basic Sciences, Kolkata, November 19-21, 2013.

Funding Opportunities for Indian Researchers, and Artificial Neural Networks: Astronomical Applications, IUSSTF Joint Center Meeting, St. Thomas College, Kozhencheri, January 20-24, 2014.

Introduction to Small Telescopes and Backend Instruments, Astronomy of Transients with Small Telescopes, IUCAA, Pune, January 31 to February 2, 2014.

Astronomical Spectroscopy and Careers in Astronomy (2 lectures), Introductory Workshop in Astronomy and Astrophysics, Department of Physics, Manipur University, Imphal, February 10-12, 2014.

Artificial Neural Network and its Application to Astronomical Data, National Conference on Perspectives of Physics in Multi Disciplinary Research (Golden Jubilee Year), Department of Physics, University of Rajasthan, Jaipur, March 12-13, 2014.

Girjesh Gupta

Spectroscopic Observations of Coronal Loop: Basic Plasma Parameters, ASI-2014 meeting, IISER Mohali, March 20-22, 2014.

Neeraj Gupta

HI Absorption Science with SKA Phase-I (via Skype), SKA Science Assessment Workshop - Low Redshift Neutral Hydrogen, SKA Project Office, Manchester, UK, September 23-24, 2013.

Quasar Absorption Lines: TMT and Upcoming Radio Telescopes, TMT Science and Instrumentation workshop, Tokyo, Japan, October 16, 2013.

Fourier Transforms in Radio Astronomy (one lecture and a tutorial), Introductory radio astronomy school and workshop, Durban, South Africa, November 30, 2013.

Galaxies in 21-cm Absorption at z < 3.5, New Frontiers in Radio Astronomy, Durban, South Africa, December 7, 2013.

Galaxies in 21-cm Absorption at z < 3.5 The Metrewavelength Sky, NCRA, Pune, December 9-13, 2013.

Extragalactic HI, Radio Astronomy Winter School 2013, IUCAA-NCRA, Pune, December 24, 2013.

TMT Telescope Control System Management Plan, TMT TCS Conceptual Design Review, TMT Project Office, Pasadena, USA, April 2, 2014.

Molecular Absorption Line Searches using JVLA, Lunch talk, NRAO, Socorro, USA, April 9, 2014.

Ajit Kembhavi

Mega Projects in Astronomy (2 lectures), Workshop on Astronomy Research Opportunities and Challenges, MACFAST College, Thiruvalla, Kerala, August 13, 2013.

Giant Telescope (2 lectures), Conference on Astronomy Research: Opportunities and Challenges, Thiruvalla, Kerala, August 12-14, 2013.

Statistics in Astronomy-I, Kashmir University-IUCAA Workshop on Astronomical Techniques and Science with Virtual Observatories, Kashmir University, September 25, 2013.

Statistics in Astronomy –II, Kashmir University-IUCAA Workshop on Astronomical Techniques and Science with Virtual Observatories, Kashmir University, September 26, 2013.

Warm Absorbers, Workshop on High Energy Emission from Active Galactic Nuclei, University of Kashmir, October 9, 2013.

The LIGO-India, Gravitational Waves Physics and Astronomy Workshop (GWPAW), IUCAA, Pune, December 19, 2013.

Astronomy from Virtual Observatory, Workshop on Radio Studies of Galaxy and Galaxy Systems, IUCAA, Pune March 4, 2014.

Sanjit Mitra

Status of LIGO-India, ASI Meeting, IISER-Mohali, March 20, 2014.

Introduction to Gravitational Wave Astronomy (lecture and hands-on session), Workshop on Gravitational Waves, IISER-Mohali, March 19, 2014.

Introduction to Gravitational Wave Astronomy, for Pune University and visiting Presidency University students, IUCAA, February 24, 2014.

BipoSH Analysis on PLANCK, PLANCK Joint Meeting, Paris, February 06, 2014.

Introduction to Gravitational Wave Astronomy (2 lectures), IUCAA club, November 27-28, 2013.

LIGO-India Computing Requirements, LIGO-India Meeting, IPR, Gandhinagar, November 11, 2013.

Introduction to Gravitational Wave Astronomy, Presidency University, Kolkata, October 09, 2013.

Introduction to Gravitational Wave Astronomy, IISER-Kolkata, October 07, 2013.

Introduction to Gravitational Wave Astronomy, SRTM University, Nanded, September 28, 2013.

LIGO-India High Performance Computing, TMT-LIGO-CDAC Meeting, IUCAA, September 18, 2013.

Stochastic Gravitational Wave Background (SGWB) from Localized Sources: Directed Radiometer Search, FTAG, IIT-Gandhinagar, September 06, 2013.

Radiometer Searches for Anisotropic Stochastic Gravitational Wave Background, SGWB in the Advanced Detector Era, OCA, Nice, July 04, 2013.

Extracting Science from the Planck Mission, NCRA, May 03, 2013.

Extracting Science from the Planck Mission, IIA, Bangalore, April 17, 2013.

Extracting Science from the Planck Mission, ICTS, Bangalore, April 16, 2013.

Vijay Mohan

Photometry Techniques (2 lectures), Refresher Course in Astronomy and Astrophysics for College and University teachers and Vacation Students' Programme, IUCAA, Pune, May 10 and 13, 2013.

J.V. Narlikar

A Critique of the Big Bang Cosmology, Indian Institute of Technology, Mandi, April 1, 2013.

A Cambridge Controversy and its Aftermath in Radio Astronomy, EYES Lecture Series, University of Mumbai, April 13, 2013.

A Search for Micro-Life in the Earth's Atmosphere, National Atmospheric Research Laboratory, Tirupathi, May 6, 2013.

Why Study Astronomy?, Refresher Course in Astronomy and Astrophysics for College and University Teachers and Vacation Students' Programme, IUCAA, Pune, May 10, 2013.

Analytical Thinking, Refresher Course in Astronomy and Astrophysics for College and University Teachers and Vacation Students' Programme, IUCAA, Pune, May 13, 2013.

Alternative Cosmology (2 lectures), Refresher Course in Astronomy and Astrophysics for College and University Teachers and Vacation Students' Programme, IUCAA, Pune, June 5 and 6, 2013.

Analytical Reasoning in Science and Beyond, University of KwaZulu-Natal, South Africa, August 5, 2013.

A Synthesis of General Relativity and Mach's Principle and its Observed Consequences, South African Gravity Society Meeting, South Africa, August 8, 2013.

Searches for Alien Microlife in the Earth's Atmosphere, Durban University of Technology, South Africa, August 13, 2013.

The Case for an Alternative Cosmology, University of KwaZulu-Natal, South Africa, August 15, 2013.

Searches for Life in the Universe, Department of Microbiology, University of Pune, Pune, September 21, 2013.

A Search for Microlife in the Earth's Atmosphere, IUCAA, Pune, October 9, 2013.

An Alternative Cosmology, IUCAA, Pune, November 6, 2013.

The Quasi-Steady State Cosmology: A Status Report, Department of Physics, Cochin University of Science and Technology, Kochi, November 18, 2013.

Are We Alone in the Universe?, Diamond Jubilee Lecture, Dayalbagh Educational Institute, Agra, December 7, 2013.

What a Student can Learn from the Saha Equation?, International Conference organized by the Department of Applied Mathematics, University of Calcutta at Rajabazar Science College, Kolkata, February 13, 2014.

Analytical Thinking, Presidency University, Kolkata- for Visiting students, IUCAA, Pune, February 27, 2014.

Fostering Science Temper, Institute of Bioinformatics and Biotechnology, University of Pune, Pune, February 28, 2014.

T. Padmanabhan

Cosmological Constant, its Problem(s) and the Solution, TIFR Centre for Interdisciplinary Sciences (TCIS), Hyderabad, May 21, 2013.

Cosmological Constant, its Problems and a Possible Solution, University College London, June 10, 2013.

Cosmological Constant, its Problems and a Possible Solution, Institute for Astronomy, The University of Edinburgh, June 13, 2013.

Conceptual Conundrums in Cosmology, [Vainu Bappu Memorial Lecture], Indian Institute of Astrophysics, Bangalore, July 5, 2013.

The Emergent Gravity Paradigm and the Cosmological Constant, Karl Schwarzschild Meeting, Frankfurt Institute for Advanced Studies (FIAS), Frankfurt, July 22-26, 2013.

Understanding Gravity, National Centre for Radio Astrophysics, Pune, February 24, 2014.

Cosmological Constants (2 lectures), meeting on Cosmology and the Constants of Nature, DAMPT, Cambridge, March 17-18, 2014.

Gravity: The Emergent Perspective, Queen Mary College, London, March 26, 2014.

Cosmological Constant, its Problem(s) and the Solution, Jamia Millia Islamia, Delhi, May 3, 2013.

Cosmological Constant, its Problems and a Possible Solution, Department of Applied Mathematics and Theoretical Physics, University of Cambridge, June 17, 2013.

Cosmological Constant, its Problems and a Possible Solution, ETH, Zurich, September 20- 30, 2013.

The Cosmological Constant: its Problem and a Possible Solution, Astrophysics Center, Portsmouth, March 20, 2014.

Gravity: The Emergent Perspective, University of Oxford, March 21, 2014.

The Cosmological Constant, its Problem and a Possible Solution, Imperial College, London, March 25, 2014.

Universe: Its History and Mysteries, India International Centre, Delhi, Friday, May 3, 2013.

The Two Edges of Theoretical Physics, 26th Kerala Science Congress, Wayanad, P.R. Pisharaty Memorial Lecture, January 30, 2014.

The Accelerating Universe, Rutherford Appleton Lab, March 24, 2014.

A.N. Ramaprakash

Instrumentation Initiatives at IUCAA, MACFAST, Kerala, August 13, 2013.

Software in Astronomy, MACFAST, Kerala, August 13, 2013.

Indian Participation in the Thirty Metre Telescope, CDAC, Thiruvanthapuram, September 18, 2013

IUCAA Laboratory Initiatives, IUCAA, September 26, 2013.

Instrumentation Initiatives at IUCAA, TMT Science and Instrumentation Meeting, IIA, Bengaluru, January 17, 2014.

Instrumentation Interests for India in TMT, TMT Science and Instrumentation Meeting, IIA, Bengaluru, January 17, 2014.

IUCAA Instrumentation Laboratory, TMT Science and Instrumentation Meeting, IUCAA, Pune, January 20, 2014

Tarun Souradeep

LIGO-India: An Indian Adventure in GW Astronomy, APLI (Satellite meet of GWPAW-13), IUCAA, Dec 20, 2013.

Astronomy and Astrophysics in India: Emerging Challenges in Data Flow, 2nd Annual Workshop of the National Knowledge Network (NKN). October, 17, 2013.

Probing Beyond the Cosmic Horizon, Jayant@75, IUCAA, Jul 18, 2013.

Isotropy Violation of Planck CMB Map, GR-20, Warsaw, Poland, July 7, 2013 (On behalf of the Planck Collaboration)

Testing the Isotropic Cosmos with CMB, Cosmology Seminar, Imperial College, London, July 5, 2013.

Isotropy of Planck CMB map in BipoSH Representation, 47th ESLAB Meeting on The Universe as Seen by

Planck, ESA/ESTEC, Noordwijk, Netherlands, Apr. 2-5, 2013. (On behalf of the Planck Collaboration)

Comely or Foxy Universe Revealed by Planck?, Our Universe: Revelation from Planck, IIA, Bangalore, Apr. 17-18, 2013

Universe Revealed by Planck: Simplicity or Duplicity? Planck Day, ICTS, Bangalore, Apr. 16, 2013

Planck's Cosmos: Simplicity or Duplicity, FTAG-2013, IIT Gandhinagar, Sep. 6, 2013

R. Srianand

Science with SALT, SALT Science Meeting, Poland, 2013.

Probing the Remote Universe with QSO Absorption Line, CEFIPRA meeting, Paris, 2013.

Science with SALT, Science Meeting in Mafekine, SA, November 2013.

Cold Gas at High-z, UKZN, Durban, November 2013

Outflows in QSOs, Workshop on Galaxies: Normal and Active, Kashmir University, November 14 - 17, 2013.

Probing the Universe with QSO Absorption Line, IIA, Bangalore, June11, 2013.

Kandaswamy Subramanian

Fluctuation to Mean Field Dynamos: The Search for Coherence, Nordita Astrophysics Seminar, Nordita, Sweden April 2013.

Probing the Universe using High Redshift Galaxies, Astronomy Seminar, Stockholm University, Sweden, April 2013.

Cosmic Magnetism: The Search for Coherence, Jayant@75, IUCAA, Pune, July 2013.

Turbulent dynamos at large R_m: The Search for Coherence, Indo-French Seminar, IISc, Bangalore, September 2013.

Fluctuation to Mean Field Turbulent Dynamos: The Search for Coherence, Colloquium, IIA, Bangalore, November 2013.

Probing the Universe using High Redshift Galaxies, Astronomy Seminar, IIA, Bangalore, November 2013.

Primordial Magnetic Fields: Origin, Evolution and Signatures, Symposium on Astro-particle and Nuclear Physics, Jamia Millia Islamia, Delhi, January 2014.

Durgesh Tripathi

The Sun: Our Star, IUCAA, School Students, February 8, 2014.

The Violent Sun, Frontiers in Physics, Fergusson College, Pune, January 21, 2014.

The Dynamic Sun, Radio Astronomy Winter School, IUCAA-NCRA, Pune, December 24, 2013.

Waves and Flows in Solar Atmospshere, 2nd Asia Pacific Solar Physics Meeting, Hangzhou, China, October 24-26, 2013.

Heating of Solar Active Regions, Royal Observatory, Belgium, July 2013.

Asymmetries in Coronal Spectral Lines and their Emission Measure, Coronal Loops Workshop - 6, La-Roche, Belgium, June 25-27, 2013.

Heating and Dynamics of Solar Active Regions, Kiepenheuer-Institut for Solar Physics, Freiburg, Germany, June 2013

Heating of Solar Active Region Cores, Solar Physics Seminar, Max-Planck-Institute for Solar System Research, Katlenburg-Lindau, Germany, June 2013.

Introduction to the Sun (2 lectures) Vacation Student Programme and Refresher Course for University and College Teachers, May-June 2013.

Solar Active Region Heating, Astronomy Seminar, Indian Institute of Science, Bengaluru, April 2013.

(b) Lecture Courses

Dipankar Bhattacharya

Introduction to Astronomy and Astrophysics (4 lectures), Vacation Students' Programme /Refresher Course in Astronomy and Astrophysics, IUCAA, May 6 - 9, 2013.

Gulab Dewangan

Compact Objects (2 lectures), ***Accretion Processes*** (2 lectures), Vacation Students' Programme/Refresher Course in Astronomy and Astrophysics, IUCAA, May 27 - 30, 2013.

Girjesh Gupta

Solar Physics (3 lectures), IUCAA-Tezpur University Workshop on Solar Physics, Tezpur University, Assam, December 18-20, 2013.

Ranjan Gupta

Stellar Spectroscopy and Spectroscopic Instrumentation (3 lectures), Vacation Students' Programme / Refresher Course in Astronomy and Astrophysics, IUCAA, May 14 - 16, 2013.

Ajit Kembhavi

Stars (4 lectures), Vacation Students' Programme/Refresher Course in Astronomy and Astrophysics IUCAA, May 2013.

Ranjeev Misra

Accretion Processes in Astrophysics (4 lectures), Vacation Students' Programme/Refresher Course in Astronomy and Astrophysics, IUCAA, May 2013.

Radiative Processes in Astrophysics (3 lectures) Introductory School in Astronomy, R.G. University, Itanagar, Arunachal Pradesh, September 2013.

Radiative and Accretion Processes in Astrophysics (3 lectures) Workshop on Astronomical Techniques, Kashmir University, Srinagar, September 2013.

Jayant Narlikar

Cosmology (5 lectures), Centre for Excellence in Basic Sciences, Mumbai, April 9, 10, 12, 16, 17, 2013.

Action at a distance electrodynamics (6 lectures), IUCAA, Pune, October 14, 15, 21, 23, 28, 30, 2013.

T. Padmanabhan

Special and General Relativity (4 lectures), Vacation Students' Programme / Refresher Course in Astronomy and Astrophysics, IUCAA, May 6 - 9, 2013.

A.N. Ramaprakash

Detectors and Instrumentation (4 lectures), Vacation Students' Programme / Refresher Course in Astronomy and Astrophysics, IUCAA, May 6 - 9, 2013.

Tarun Souradeep

Cosmology (4 lectures), Vacation Students' Programme /Refresher Course in Astronomy and Astrophysics, IUCAA, June 3 - 6, 2013

R. Srianand

Galaxies and Active Galactic Nuclei (4 lectures), Vacation Students' Programme/Refresher Course in Astronomy and Astrophysics, IUCAA, May 29-31, 2013

Kandaswamy Subramanian

Fluid Plasmas (3 lectures), ***Structure Formation in the Universe*** (1 lecture), Vacation Students' Programme / Refresher Course in Astronomy and Astrophysics, IUCAA, May 27 - 30, 2013.

S. N. Tandon

UVIT (ASTROSAT) (2 lectures) Vacation Students' Programme/Refresher Course in Astronomy and Astrophysics, IUCAA, May 22 - 23, 2013.

Durgesh Tripathi

Solar Physics (3 lectures) Introductory Solar Physics Workshop, Tezpur University, Assam, December 17-19, 2013.

SCIENTIFIC MEETINGS AND OTHER EVENTS

REFRESHER COURSE IN ASTRONOMY AND ASTROPHYSICS

The Refresher Course in Astronomy and Astrophysics for college and university teachers was held during May 6 -June 7, 2013.The Refresher Course was coordinated by Sanjit Mitra.

[For details see Khagol, Issue No.95, July 2013]

THE VACATION STUDENTS' PROGRAMME (VSP)

The Vacation Students' Programme (VSP) was also simultaneously conducted during May 6 – June 21, 2013. The VSP was coordinated by R. Srianand.

[For details see Khagol, Issue No.95, July 2013]

JAYANT @75

Professor Jayant Vishnu Narlikar, Founder Director of IUCAA, completed 75 years of age on July 19, 2013. To celebrate this milestone, a meeting was organized at IUCAA during July 18-19, 2013. Professor Narlikar and Smt. Mangala Narlikar were felicitated during the meeting, after which Professor Narlikar gave a brief talk, wherein he said that he was not fond of the Big-Bang Theory and Chitale's Bakarwadi, for which Pune is so famous.

[For details see Khagol, Issue No.96, October 2013]

GRAVITATIONAL WAVE PHYSICS AND ASTRONOMY WORKSHOP

The seventeenth Gravitational Wave Physics and Astronomy Workshop was held at IUCAA during December 17-20, 2013. Sukanta Bose coordinated this workshop. The next GWPAW will be held during June 17-20, 2015 in Osaka, Japan.

[For details see Khagol, Issue No.97, January 2014]

SILVER JUBILEE FOUNDATION DAY LECTURE

The Silver Jubilee Foundation Day Lecture, titled "Building Scientific Institutions: The IUCAA Story" was delivered by the Founder Director, Professor Jayant Narlikar, on December 29, 2013 in the Chandrasekhar Auditorium.

[For details see Khagol, Issue No.97, January 2014]

MIT-IUCAA WORKSHOP ON X-RAY STUDIES OF TRANSIENT ASTRONOMICAL SOURCES

MIT-IUCAA workshop on X-ray Studies of Transient Astronomical Sources was held at IUCAA during January 13 - 24, 2014. On January 17, a special session on Transients with ASTROSAT brought together more than 15 senior astronomers from all over India to interact with the workshop participants. The workshop was coordinated by Dipankar Bhattacharya.

[For details see Khagol, Issue No.98, April 2014]

WORKSHOP ON ASTRONOMY OF TRANSIENTS WITH SMALL TELESCOPES

Workshop on Astronomy of Transients with Small Telescopes was organised at IUCAA during January 31 - February 2, 2014. The workshop was coordinated by Gulab Dewangan and Samir Dhurde.

[For details see Khagol, Issue No.98, April 2014]

WORKSHOP ON PYTHON PROGRAMMING IN ASTRONOMY

The first ever workshop on Python Programming in Astronomy was held in IUCAA during February 17 - 21, 2014. A special talk was also given by Ashish Mahabal focusing on important practices in coding. Kaustubh Vaghmare coordinated this workshop.

[For details see Khagol, Issue No.98, April 2014]

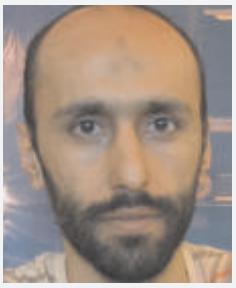
WORKSHOP ON RADIO STUDIES OF GALAXIES AND GALAXY SYSTEMS

A 3 day workshop on Radio Studies of Galaxies and Galaxy Systems was organized at IUCAA during March 4 - 6, 2014. R. Srianand and Gopal Krishna coordinated this workshop.

[For details see Khagol, Issue No.98, April 2014]

Ph.D. Programme

Four IUCAA Research Scholars, Hadi Rahmani Bayegi (Guide: R. Srianand), Sanved Kolekar (Guide: T. Padmanabhan), Sandeep Kumar (Guide: Dipankar Bhattacharya), and Sowgat Muzahid (Guide: R. Srianand), have defended their Ph.D. theses submitted to Jawaharlal Nehru University (by Hadi Rahmani Bayegi and Sanved Kolekar) and to the University of Pune (by Sandeep Kumar and Sowgar Muzahid), during the year of this report.



Hadi Rahmani Bayegi

Title of the thesis:

Exploring the High Redshift Universe using Quasar Spectroscopy

Quasar absorption lines provide unique tools to study the physical conditions of the interstellar medium of high redshift galaxies. In addition, they allow us to perform precise tests to check the constancy of fundamental constants of physics at different cosmological epochs. Such aspects of the quasar absorption lines form the basis of the work presented in this thesis.

Employing a spectral stacking technique, we have searched for the average Lyman α emission from high-z damped Lyman α (DLA) galaxies detected in the Sloan Digital Sky Survey (SDSS) quasar spectra. In Chapter 2, we have used a sample of 341 DLA galaxies of mean redshift $<z> = 2.86$ and $N(H_I) \geq 10^{20.62}$ cm^{-2} to place a 3σ upper limit of 3.0×10^{-18} ergs cm^{-2} on the Lyman α flux emitted within $\sim$ 1.5 arcsec (or 12kpc) from the quasar line of sight. This limit is deeper than the limit one achieves in most surveys for faint Lyman α emitters. In addition, our observations based on Faint Object Spectrograph and Camera at the New Technology Telescope at the European Southern Observatory (ESO) for Lyman α emission from 7 DLA galaxies resulted in non-detection of Lyman α emission from these galaxies. The lack of Lyman α emission in DLA galaxies is consistent with the in situ star formation, for a given $N(H_I)$, being less than what is seen in local galaxies. Thus, the overall DLA population seems to originate from the low-luminosity end of the high-redshift Lyman α emitting galaxies and/or to be located far away ($>$ 12 kpc) from the star-forming regions. The latter may well be true since we detect strong O VI absorption in the stacked spectrum, indicating that DLA galaxies are associated with a highly ionized phase. We have found the contribution of DLA galaxies to the global star formation rate density to be comparatively lower than that of Lyman break galaxies of similar redshift.

A comparison between the 21-cm absorption redshift with that of resonance metal lines can be used to constrain the variation of $x \equiv g_p \alpha^2 \mu$, to a level of $\Delta x/x \sim 10^{-6}$, where g_p is the proton gyromagnetic factor, α is the fine structure constant and μ is the proton-to-electron mass ratio. In Chapter 3, we have presented high-resolution optical spectra obtained with the Ultraviolet and Visual Echelle Spectrograph at the Very Large Telescope (VLT/UVES) and 21-cm absorption spectra obtained with the Giant Metrewave Radio Telescope and the Green Bank Telescope of five quasars along the line of sight of which 21-cm absorption systems at $1.17 < z < 1.56$ have been detected previously. We have also presented milliarcsecond-scale radio images of these quasars obtained with the Very Large Baseline Array. We have elaborated detailed analysis based on repeated Voigt profile fitting, cross-correlation analysis and comparing with the Keck spectra (whenever available) to accurately quantify the systematic errors in our $\Delta x/x$ measurements. Making use of four of these systems, we have put a robust constraint of $\Delta x/x = (0.0 \pm 1.5) \times 10^{-6}$ at the mean redshift of $< z > = 1.36$ corresponding to a look-back time of $\sim$ 9 Gyr. This is the most stringent constraint ever obtained on $\Delta x/x$. Assuming the constancy of other constants, we get $\Delta\alpha/\alpha = (0.0 \pm 0.8) \times 10^{-6}$, which is a factor of 2 better than the best constraints obtained so far using the many-multiplet method. On the other hand, assuming that α and g_p have not varied, we have derived $\Delta\mu/\mu = (0.0 \pm 1.5) \times 10^{-6}$, which is again the best limit ever obtained on the variation of μ over this redshift range.

The value of $\Delta\mu/\mu$ at $z \geq 2$ can be estimated using H_2 absorption lines, occasionally associated with DLAs, as their wavelengths are sensitive to the value of μ. In Chapter 4, we have presented a systematic analysis of the H_2 absorption lines from the $z_{abs} \sim 2.4018$ DLA system towards HE 0027-1836 observed with VLT/UVES as a part of the ESO Large Programme, "The UVES large programme for testing fundamental physics". We have performed cross-correlation analysis between 19 individual exposures taken over three years' time and the combined spectrum to check the wavelength calibration stability. We have found that $\Delta\mu/\mu = (9.7 \pm 8.3) \times 10^{-6}$ after excluding one of the exposures that is found to be affected by a large velocity offset with respect to the rest of the spectra. We have also noticed a possible wavelength dependent velocity drift especially in the data taken in 2012. We conform and quantify this systematic effect by analysing the available asteroids spectra taken with UVES. Applying corrections to the velocity drift using the relationship found for asteroid spectra and using the combined spectrum of 18 exposures we get $\Delta\mu/\mu = (5.2 \pm 8.6) \times 10^{-6}$. Our analysis of H_2 absorption seen towards HE 0027-1836 confirms the stability in μ at $z \sim 2 - 3$ found in previous studies at the level of $|\Delta\mu/\mu| \leq 10^{-5}$.

In Chapter 5, we have provided a summary of our results along with the main conclusions of the thesis. In addition, prospects for the future works are also presented.

Sanved Kolekar

Title of the thesis:

Gravitational Dynamics and Thermodynamics of Horizons

Various independent arguments suggest that we require a quantum theory of gravity, which combines the principles of General Relativity and Quantum Field Theory, to explain physical phenomenon at length scales of the order of the Planck length. Numerous proposals have been made to construct such a theory, though it would be safe and fair to say that, as of now, we do not have a completely satisfactory theory of quantum gravity. However, at length scales larger than the Planck scale, one expects the (as yet unknown) theory of quantum gravity to reduce to a semiclassical framework, in which gravity is described by the geometry of spacetime with the quantum fields propagating in the curved spacetime background. Over the past few decades, this framework has yielded a variety of results some of which, when looked upon from a proper perspective, could possibly suggest a guiding principle to construct the underlying quantum gravity theory. One such remarkable consequence is the connection between horizon dynamics and the laws of thermodynamics. The main aim of this thesis is to explore this connection and its possible implications on the full theory of quantum gravity.

This peculiar relationship between thermodynamics and dynamics of horizons, known for four decades, is now being slowly recognized as indicating a more fundamental principle in which gravity can be viewed as an emergent phenomenon like fluid mechanics or elasticity. Such a point of view draws support from several pieces of evidence of which we may mention as following:

(a) The field equations of gravity reduce to a thermodynamic identity on the horizons in a wide variety of models much more general than just Einstein's gravity.

(b) It is possible to obtain the field equations of gravity again for a wide class of theories from purely thermodynamic considerations.

(c) One can obtain an equipartition law analogous to E= (1/2)nkBT for the density n of microscopic degrees of freedom in any static geometry providing a direct window to microscopic physics in the thermodynamic limit.

(d) From the perspective of the fluid/ gravity correspondence, the projection of Einstein's field equations on to any

null surface in any spacetime reduces exactly to the NavierStokes form when viewed in the local inertial frame.

As emphasized in the literature, such results do more than establish the connection or analogy between horizon dynamics and the laws of thermodynamics, they actually speculate that the spacetime metric may not represent the true dynamical degrees of freedom of the underlying theory of quantum gravity. In such an approach, gravity is best viewed as an emergent phenomenon, where the geometrical variables like the spacetime metric, etc. are derived concepts (like for example, pressure, density, etc. of a gas) and the dynamical equations governing them can be derived from the long wavelength limit of the dynamics of the true underlying microscopic degrees of freedom of quantum theory of gravity.

In Chapter 1, we have introduced some basic terminologies as well as review some of the standard results in the study of thermodynamics of horizons, fluid/gravity correspondence in the context of the membrane paradigm and classical as well as quantum field theory effects on curved backgrounds, which form the background for the results presented in the thesis.

Given the fact that one can obtain the field equations for gravity from an action functional in which the metric is varied raises the following question: If gravity is indeed an emergent phenomenon, should not the action functionals leading to the field equations of gravity contain some signature of this fact ? After all, field equations "know" that there exist an alternative, emergent, interpretation for the dynamics and hence, it seems reasonable to assume that this information must be embedded in the action functionals describing theories of gravity in some manner. The first part of the thesis addresses this question. In Chapter 2 and Chapter 3, we have demonstrated that there is sufficient evidence which suggests that action functionals do reflect the fact that the description of gravity is an emergent one.

Another theme of this thesis is to study the thermodynamics, in particular, the behaviour of the entropy of (i) test systems on a given curved background spacetime with a horizon and (ii) self gravitating systems on the verge of forming a black hole in higher curvature theories of gravity; and compare the results with the Wald entropy of black hole in the corresponding theory of gravity. In a situation involving both matter sources and gravity, it is not quite clear what precisely is the inter-relationship between the usual thermodynamic entropy of matter and the entropy of the horizon.

The two extreme views which are possible would be: (i) The entropy of the horizon is the same as the entropy of the matter source (which we call as the extrinsic approach), the gravity of which leads to the formation of the horizon and (ii) the horizon entropy arises from microscopic quantum structure of spacetime (which we call as the intrinsic approach). But, within the context of Einstein's gravity, it is very difficult to discriminate between these two approaches. This is because, in Einstein's theory, entropy of a horizon is proportional to its area, which has a simple geometrical meaning. On the other hand, the proportionality between horizon entropy and area does not extend to more general class of gravitational theorie~ in which the entropy is given by a prescription due to Wald which essentially identifies the horizon entropy with a suitably defined Noether charge, which has been discussed in Chapter 4.

The work described in Chapter 5 analyzes the thermodynamical behaviour of a box of gas, treated as a test system located in an external spacetime with horizon, neglecting its self-gravity. It also further reinforces the essential observer dependence of thermodynamics arising principly through the Davies-Unruh effect.

Having identified the kinematical aspects involved in the description of matter entropy, we focus in Chapter 6 on the dynamical aspects by investigating the thermodynamics of gravitating systems in Lanczos-Lovelock models of gravity. In particular, we have shown that the extrinsic approach of associating matter entropy with the Wald entropy of the resulting black hole, fails and can, in principle, account for only a fraction of the total black hole entropy. We speculate on the implications of this result on the emergent paradigm of gravity.

In Chapter 7, we move from the static regime to a dynamical scenario and extend the proposal of Wald entropy to black hole horizons in Lanczos-Lovelock gravity for quasistationary physical processes by proving that the proposed quantity for entropy always increases monotonically in such processes. The last part of the thesis is devoted to the study of the thermal aspects of the Davies-Unruh bath.

We have devoted Chapter 8 to the study of thermal properties of the Davies-Unruh bath. A known, interesting, feature of the Davies-Unruh effect is that an uniformly accelerated observer sees an isotropic thermal spectrum of particles even though there is a preferred direction in this context, determined by the direction of the acceleration g.

We have investigated the thermal fluctuations in the Unruh bath by studying the Brownian motion of particles in the bath, especially as regards to isotropy. In particular, we have employed the Unruh-DeWitt detector to obtain the form of the drag force acting on the particles drifting in different directions with respect to the direction of acceleration of the Rindler observer. We have found that the thermal fluctuations are anisotropic and induce different frictional drag forces on the Brownian particle depending on whether it has a drift velocity along the direction of acceleration g or in a direction transverse to it. Using the fluctuation-dissipation theorem, we have argued that this anisotropy arises due to quantum correlations in the fluctuations at large correlation time scales. In the large frequency limit, the isotropy is shown to be restored as expected.

Finally, Chapter 9 summarizes the main results of the thesis, their implications and future outlook suggested by the present work.

Sandeep Kumar

Title of the thesis:

Accretion Induced Evolution of Neutron Star Magnetic Fields

Neutron stars are strongly magnetized objects, with surface field strengths in the range 10^8 to 10^{15} G. The long-term evolution of these magnetic fields is a subject of abiding interest, but with many open questions. Observations suggest that neutron stars that undergo sustained accretion of matter from a companion tend to display a long-term reduction of their magnetic field strength. Among many explanations that have been proposed in the literature for such an evolution, a popular one involves the screening of the field by the incoming, highly conducting plasma during accretion. If this is indeed true then large distortions in the star's magnetic field are expected during an ongoing accretion process.

One way to directly probe the strength and the structure of the magnetic field of an accreting neutron star is to observe the Cyclotron Resonance Scattering Features (CRSF), also referred to as cyclotron lines, originating in the accretion region near the stellar surface. The resonance energy of these features are determined by the local field strength, and their profiles are shaped by the distribution of the field in the emission region. Detailed observations and accurate modelling of cyclotron lines can probe the field distortions caused by the accreting matter and yield valuable information on whether or not screening can be responsible for the secular reduction of the magnetic field of an accreting neutron star.

The work in this thesis relates to one specific aspect of this larger problem: Predicting the nature of observable CRSF given the physical properties of the emission region. We have presented here a versatile Monte-Carlo radiative transfer code that we have developed for this purpose. The code is designed to handle arbitrary spatial variations of the magnetic field strength and of the physical properties of the accreting plasma. It accepts an input continuum and computes the effect of resonant scattering, absorption and emission processes that re-shape the emergent spectrum. Subsequently, the spectra as would be observed by a distant observer are computed, taking into account the effects of gravitational redshift and light bending, caused by the extremely strong gravity of the neutron star.

We have applied our code to predict the observable spectra from different emission geometries usually invoked for the origin of cyclotron lines in massive X-ray binary systems. The cases addressed in this thesis include an optically thin slab near the stellar surface, an accretion mound formed by accumulation of the accreted matter and an

accretion column representing the zone of a settling flow onto the star.

Our results show that the locally emergent spectra from the emission volume are significantly anisotropic. However, in the presence of strong light bending, the anisotropy reduces considerably. This averaging also drastically reduces the strength of harmonics higher than second in the observable cyclotron spectra. We have found that the uniform field slabs produce line features that are too narrow, and mounds with large magnetic distortions produce features that are too wide compared to the average widths of the spectral features observed from various sources. The column with a gently varying (dipole) field produces widths in the intermediate range, similar to those observed.

The geometries, we have explored in this thesis, however, are unable to reproduce the full range of behaviour displayed by observed cyclotron lines, indicating that in reality the emission region may have a more complex structure. Exploring structures of greater complexity would be part of our future endeavour in addressing the important question of the structure and evolution of neutron star magnetic fields.

Sowgat Muzahid

Title of the thesis:

Physics of the IGM and Evolution of the High Redshift Universe

The quasar (QSO) absorption spectroscopy has long been recognized as one of the most sensitive probes of the physical conditions of the gas in a wide variety of astrophysical environments. In particular, absorption lines seen in the spectra of distant QSOs are unique probes of intervening gas and outflows from the central active galactic nuclei (AGN). In this thesis, we have studied the absorbing gas traced by highly ionized metal line species using high resolution QSO spectra. This includes, from very high density ($n_{\rm H} \sim 10^5$ particles/cc) outflowing gas to the extremely low density ($n_{\rm H} \sim 10^{-5}$ particles/cc) intergalactic medium (IGM).

In the first part of this thesis, we have presented a detailed study of the largest sample of intervening O VI absorbers in the redshift range $1.9 \leq z \leq 3.1$, detected in high resolution ($R \sim 45{,}000$) spectra of 18 bright QSOs observed with *Very Large Telescope/Ultraviolet and Visible Echelle Spectrograph* (*VLT*/UVES). Based on Voigt profile fit and apparent optical depth (AOD) analysis, we have shown that (i) the Doppler parameters of the O VI absorption are usually broader than those of C IV, (ii) the column density distribution of O VI is steeper than that of C IV, (iii) line spread (δv) of the O VI and C IV are strongly correlated (at 5.3σ level) with δv(O VI) being systematically larger than δv(C IV), and (iv) $\delta\ v$(O VI) and δv(C IV) are also correlated with their respective column densities (at$> 5\sigma$ level) and with N (H I) (3 and 4.5σ respectively). The median column densities of H I, O VI, and C IV are found to be higher when low ions are present. N(C IV) and N(H I) are strongly correlated (at 4.3σ level). However, no significant correlation is found between N(O VI) and N(H I). These findings favour the idea that C IV and O VI absorption originate from different phases of a correlated structure and absorbers with large velocity spread are probably associated with overdense regions. The velocity offset between optical depth weighted redshifts of C IV and O VI absorption is found to be in the range $0 \leq |\Delta v(\text{O VI} - \text{C IV})| \leq 48\ kms - 1$ with a median value of 8 km s^{-1}. We do not find any evidence for the ratios N(O VI)/N(H I), N(O VI)/N(C IV) and N(C IV)/N(H I) to evolve with z over the redshift range considered here. But a lack of systems with high N(O VI)/N(H I) ratio (i.e., ≥ -0.5 dex) for $z > 2.5$ is noticeable. Similar trend is also seen for the N(C IV)/N(H I) ratio. We have compared the properties of O VI systems in our sample with that of low redshift ($z < 0.5$) samples from the literature and find that (i) the O VI components at low-z are systematically wider than at high-z with an enhanced non-thermal contribution to their b-parameter, (ii) the slope of the column density distribution functions for high and low-z are consistent, (iii) the range in gas

temperature estimated from a subsample of well aligned absorbers is similar at both high and low-z, and (iv) $\Omega_{\rm O\,VI} = (1.0 \pm 0.2) \times 10^{-7}$ for $N({\rm O\,VI}) > 10^{13.7}$ cm^{-2}, estimated in our high-z sample, is very similar to low-z estimations. Near constancy of $\Omega_{\rm O\,VI}$ possibly suggests that the O VI absorbers at high and low$-z$ may not originate from regions of similar physical conditions.

In the next part of this thesis, we have presented measurements of He II to H I column density ratio, i.e. $\eta = N({\rm He\,II})/N({\rm H\,I})$, in the high redshift IGM towards the high redshift ($z_{\rm em} = 2.885$) UV-bright ($V = 16.1$) QSO HE 2347$-$4342, using Voigt-profile fitting of the H I and He II Lyα forest. In agreement with previous studies, we have found that $\eta > 50$ in most of the Lyα forest, except in four regions where it is much smaller ($\eta \sim 10 - 20$) and therefore inconsistent with photoionization by the extragalactic UV background (UVB) radiation. Most intriguingly, we have detected O VI and C IV absorption lines in two ($z_{\rm abs} = 2.6346$ and 2.6498) of these four low η regions. Using constant density photoionization models, we have shown that, while such simple models reproduce the observed $N({\rm O\,VI})/N({\rm C\,IV})$ ratio for a range of density, they fail to reproduce low η values. On the contrary, models with high temperature (i.e. $T \geq 10^5$ K) can reproduce low values of η but not the observed $N({\rm O\,VI})/N({\rm C\,IV})$ ratio. With the help of observed b-parameters of H I and the metal lines, we have argued that the absorbing gas is a multiphase medium in which photoionized gas components coexist with a wide range of densities and temperatures. While most of the metal absorption traced by C IV comes from the relatively cool (i.e., $T \sim 3 \times 10^4$ K) gas, part of O VI and predominant contributions of H I and He II could result from a hot gas phase ($T > 10^5$ K). Hence, we conclude that collisional ionization could be one of the sources of fluctuation in η in the high-z IGM.

In the last part of this thesis, we have presented a sample of new population of associated absorbers, detected through Ne VIII $\lambda\lambda$ 770, 780 absorption, in HST/COS spectra of intermediate redshift ($0.45 < z < 1.21$) quasars. Our sample comprised of total 12 associated Ne VIII systems detected towards 8 lines of sight (none of them are radio bright). The incidence rate of these absorbers is found to be 40%. Majority of the Ne VIII systems at small ejection velocities ($v_{\rm ej}$) show complete coverage of the background source, but systems with higher $v_{\rm ej}$ show lower covering fractions (i.e. $f_c \leq 0.8$) and systematically higher values of N(Ne VIII). We have reported the detections of Na IX $\lambda\lambda$681, 694 absorption, for the first time, in three highest ejection velocity (e.g. $|v_{\rm ej}| \gtrsim 7,000$ km s^{-1}) systems in our sample. All these systems show very high N(Ne VIII) (i.e., $> 10^{15.6}$ cm^{-2}), high ionization parameter (i.e., log U $\gtrsim 0.5$), high metallicity (i.e., $Z \gtrsim Z_\odot$), and ionization potential dependent f_c values. The observed column density ratios of different ions are reproduced by multiphase photoionization (PI) and/or collisional ionization (CI) equilibrium models. While solar abundance ratios are adequate in CIE, enhancement of Na relative to Mg is required in PIE models to explain our observations. The column density ratios of high ions (i.e., O VI, Ne VIII, Mg X etc.) show very narrow spread. Moreover, the measured $N({\rm Ne\,VIII})/N({\rm O\,VI})$ ratio is similar to what is seen in the intervening absorbers. All these suggest a narrow range of ionization parameter in the case of PIE or a narrow temperature range (i.e., $T \sim 10^{5.9\pm0.1}$ K) in the case of CIE models. The present data does not distinguish between the two alternatives. However, detection of absorption line variability with repeat HST/COS observations will allow us to (i) distinguish between these alternatives, (ii) establish the location of the absorbing gas and (iii) understand the mechanism that provides stability to the multiphase medium. These are important for understanding the contribution of associated Ne VIII absorbers to the AGN feedback.

Lastly, we have presented a detailed analysis of a highly ionized, multiphase and collimated outflowing gas detected through O V, O VI, Ne VIII and Mg X absorption associated with the QSO HE 0238–1904 ($z_{\rm em} \simeq 0.629$). Based on the similarities in the absorption line profiles and estimated covering fractions, we have found that the O VI and Ne VIII absorption trace the same phase of the absorbing gas. Simple photoionization models can reproduce the observed N(Ne VIII), N(O VI) and N(Mg X) from a single phase, whereas the low ionization species (e.g., N III, N IV, O IV) originate from a different phase. The measured $N({\rm Ne\,VIII})/N({\rm O\,VI})$ ratio is found to be remarkably similar (within a factor of ~ 2) in several individual absorption components kinematically spread over ~ 1800 km s^{-1}. Under photoionization this requires a fine tuning between hydrogen density ($n_{\rm H}$) and the distance of the absorbing gas from the QSO. Alternatively, this can also be explained by collisional ionization in hot gas with $T \geq 10^{5.7}$ K. Long-term stability favours the absorbing gas being located outside the broad line region (BLR).

Summary and future prospects of this thesis work are given at the end.

COMPUTER CENTRE

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

During the academic year 2013-2014, the OM4 Multimode fibre optic cable was laid to support 10G backbone Campus Local Area network at IUCAA. Currently, the WiFi backhaul is being done through WiFi bridges. With the newly laid fibre optic cables in the residential campus, the WiFi Access Points (AP) would be connected directly to the wired media bypassing the WiFi backhaul, thus improving the overall performance of WiFi Network.

Various applications hosted on individual physical servers, have been consolidated and virtualized on two fat physical servers and a common 3 PAR storage using VMware vShere with Operations Management software. These virtual servers provide benefits such as high availability, load balancing, faster deployment, lower energy use, simpler upgrades and ease of management. The services namely 1. Zimbra Colloboration Suit (ZCS – Email service) 2. Papercut (Printer monitoring tool) 3. SonicWall log server 4. AD (Active Directory) 5. iOAS (iucaa Office Automation System) 5. LDAP (Lightweight Directory Access Protocol) 6. Vizier Mirror site and 7. CRTS (Catalina Real Time Skysurvey) have been upgraded and migrated from physical servers to virtual servers.

The centralized Network Filesystems, served from 7 year old EVA storage, was migrated to higher capacity DDN storage in October 2013.

In January 2014, ZCS email service was upgraded from version 6.0.18_GA to 8.0.6_GA_5922 on a virtual server. It was done in stages lasting two months with least interruptions. When upgraded, the users had their data in tact with the better front end and features. The new email server could be sized with ease under virtualized server environment available at IUCAA as the physical servers needed was two during the migration process.

The Coter 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

In the period under review, the IUCAA library added 201 books, 241 eBooks and 500 bound volumes of journals taking the total collection to 25,413 which include major collections in astronomy and astrophysics, physics, mathematics, computer and electronics, supported by literature in other walks of life. The library subscribes to 126 journals, in print and online. In addition, the library also receives complimentary access to e-journals in astronomy and astrophysics not subscribed by the IUCAA library, courtesy INFLIBNET, Ahmedabad .

The library received and fulfilled 196 full-text article requests from 78 academics (including students) through email/post/in-person, inter-library loan requests for 04 books from FORSA and other libraries.
The library is equipped with state-of-the-art facilities such as a high-resolution scanner, digital photocopier, user terminals and wireless connectivity and it serves as the main resource library in Astronomy and Astrophysics in the university sector. It is open all round the year except on the three national holidays and is extensively used by the in-house users as well as associates, students, amateur astronomers, teachers and visitors coming to IUCAA.

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 is made available through the IUCAA institutional repository set up using DSpace. Online access to the IUCAA Bulletin and the Annual Report is provided using Open Journals

System (OJS). The library provides access to astronomy related CD/DVDs as well as recorded lectures delivered by Professor T. Padmanabhan through the Network Assisted Server (NAS), which are accessible on a username and password basis.

IUCAA GIRAWALI OBSERVATORY (IGO)

Observations at IGO were mostly limited to those programmes that required short exposures as the auto-guider was not functional. In March 2014, a new auto-guider was procured. It has now been tested and installed on the telescope, and now it is functioning well and the telescope is back to its normal operation. During 2013-14, based on the observations taken from IGO, a total of 10 research papers have been published.

TIRCAM2, an infra red instrument developed by TIFR was tested successfully on the IGO telescope.

VIRTUAL OBSERVATORY - INDIA

VOI-Phase II is the third generation of the VOI projects hosted at IUCAA in collaboration with Persistent Systems Ltd (PSL), Pune and partially funded by the Ministry for Communication and Information Technology, Government of India. In its fourth year, the project has focused on the following projects:

The Catalina Real-Time Transient Survey is a synoptic astronomical exploration that covers thirty three thousand square degrees of the sky in order to discover rare and interesting transient phenomena. Under this project, IUCAA will be the primary server of all CRTS data, consisting of 9 terabytes of catalogue data and 24 terabytes of images. The primary responsibility of VO-India was to establish a functionally viable mechanism for querying this vast quantity of data in a speedy manner. A procedure was established to process the data and images without compromising their integrity or scientific usability. In the process of establishing the procedure for handling images, several technical challenges were encountered and addressed, with help from academics with domain expertise. These challenges; some generic and some unique to CRTS; and their solutions are documented for future reference. All CRTS data is now being served through a web interface designed by VO-India and refined and improved with feedback from users. The CRTS project has been the major focus of VO-India in the past year.

VO-India undertook the final installation and user introduction of the Southern African Large Telescope VO Data Archive System (SALT-VODAS), which was developed by us based on requirements from the SALT community. Prior to final deployment, the application was integrated with the SALT science database hosted on their servers. The application is now live and has been announced to the SALT community.

The statistical analysis tool AstroStat was augmented on the technical as well as domain front. More tests were added, mostly to incorporate multiple types of regression analysis. Functionally, the data loading speeds were improved by developing new scripts for the same and data manipulation was introduced by adding a "column creation" feature.

As a part of student projects under VO-India, Prerak Garg, a student from Vellore Institute of Technology (VIT) has made a simple statistical analysis and curve plotting tool for Android tablet devices. The app, named "Stat-Lite", will be deployed on the Aakash tablets, which are widely distributed among school students in India. Stat-Lite implements basic statistical routines in Java and has an attractive and easy-to-use interface. Simple ready-to-go examples for the statistical routines are embedded within the app to encourage learning. Curve plotting for Trigonometric, Logarithmic, Exponential, Hyperbolic, Conic sections and user defined functions are supported.

As a part of the public outreach effort, VO-India has contributed to a four day and a two day workshop organized respectively by the University of Kashmir in Srinagar and the University of North Bengal in Siliguri. The workshops were organized in association with IUCAA Resource Centers and titled "Introduction to Astronomical Techniques and Virtual Observatory".

PUBLIC OUTREACH HIGHLIGHTS

SCHOOL STUDENTS' SUMMER PROGRAMME

IUCAA's outreach group conducted the regular School Students' Summer Programme as well as an Astronomy Summer Camp during April-May 2013, for six weeks. A total of one hundred and fifty students of classes VIII/IX/X have participated in these programmes, who were nominated by their respective schools.

For details see Khagol, Issue No. 95, July 2013]

ASTRONOMY SUMMER CAMP

Astronomy Summer Camp was conducted with 125 school students in total, who got to work at the IUCAA Muktangan Vidnyan Shodhika in the month of May. The programme was coordinated by Samir Dhurde.

For details see Khagol, Issue No. 95, July 2013]

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OUR DYNAMIC SUN

On September 19, 2013, Helen Mason, Solar Astronomer from the University of Cambridge, gave an evening public lecture at the Chandrasekhar Auditorium, IUCAA.

[For details see Khagol, Issue No.96, October 2013]

NATIONAL SCIENCE DAY CELEBRATIONS – 2014

The National Science Day - 2014 was celebrated with great enthusiasm and efficiency by IUCAA members and visitors. The occasion saw a great response, and around eight thousand people were estimated to have been to IUCAA during the celebrations on three different days.

The IUCAA, Pune campus was opened to the general public on the National Science Day, February 28. Various programmes were arranged with voluntary contributions from IUCAA staff and family. The visitors were welcomed and guided through the various displays while they discovered the wonders of the Universe.

[For details see Khagol, Issue No.98, April 2014]

S. Jocelyn Bell Burnell (Visiting Professor at the Oxford University), the discoverer of the first radio Pulsar, visited the IUCAA MVS Exploratorium on January 6, 2014.

[For details see Khagol, Issue No. 98, April 2014]

POPULAR TALKS

Sukanta Bose

Origin of life, for School Teachers, National Science Day, IUCAA, February 2014.

Ajit Kembhavi

1. *Virtual observatories*, Inauguration Lecture, Science Forum-2013-14, MES Abasaheb Garware College, August 27, 2013.

2. *Thirty Metre Telescope*, Akashmitra, Pune, September 30, 2013.

J. V. Narlikar

1. *The amazing world of astronomy*, National Conference on Space for Students – 2013, Chandigarh, April 4, 2013.

2. *A search for micro-life in the Earth's atmosphere*, National Conference on Space for Students – 2013, Chandigarh, April 4, 2013.

3. *Strange events in our solar system*, Panjab University, Chandigarh, April 5, 2013.

4. *Angular sizes of astronomical objects*, Nehru Planetarium, Mumbai, April 16, 2013.

5. *Bavishatil Maharashtra* (Maharashtra in future) (in Marathi), a keynote address delivered in the programme "Maharashtrache Mankari" organized by CBD Foundation, Mumbai, April 30, 2013.

6. *The amazing world of astronomy*, B.M. Birla Science Centre, Hyderabad, May 8, 2013.

7. *Strange events in our solar system*, Exciting Science Group, NCL Innovation Park, Pune, June 23, 2013.

8. *Strange events in our solar system*, 2nd Saturday Lecture Programme, IUCAA, July 13, 2013.

9. *Aaplya suryamaletalya vichitra ghatana* (Strange events in our solar system) (in Marathi), 2nd Saturday Lecture Programme, IUCAA, July 13, 2013.

10. *Mathematics and physics education through puzzles, recreation and challenges*, Maharashtra State Council of Educational Research and Training, Pune, July 25, 2013.

11. *The amazing world of astronomy*, University of KwaZulu-Natal, South Africa, August 2, 2013.

12. *The amazing world of astronomy*, Indian Institute of Technology Guwahati, August 31, 2013.

13. *Strange events in our solar system*, Tezpur University, September 2, 2013.

14. *Rashtriya ekta, vidnyan aur Hindi bhasha* (National integration, science and Hindi language) (in Hindi), Directorate of Purchase and Stores, Mumbai, September 19, 2013.

15. *Living with an idea*, Ramakrishna Math and Ramakrishna Mission, Mumbai, September 28, 2013.

16. *Phalajyotishachi vaidnyanik chachani* (A scientific test of astrology) (in Marathi), College of Engineering, Pune, October 2, 2013.

17. *Cosmic illusions*, National Conference on Space and Mars Exhibition – 2013, Chandigarh, October 25, 2013.

18. *Avakashatil jeevashrushti – Shodhvata ani dhandola* (Space explorations in different ways) (in Marathi), Dr. Nagesh Dhaygude Memorial Lecture, Solapur, November 9, 2013.

19. *Searches for life in the universe*, Sixth Science Conclave, Indian Institute of Information Technology Allahabad,

December 10, 2013.

20. *Strange events in our solar system*, Sixth Science Conclave, Indian Institute of Information Technology Allahabad, December 14, 2013.

21. *Strange events in our solar system*, INSPIRE Winter Internship Programme, Pt. Ravishankar Shukla University, Raipur, December 26, 2013.

22. *Building scientific institutions: The IUCAA story*, 25th Foundation Day Lecture of IUCAA, Pune, December 29, 2013.

23. *Cosmic illusions*, Muktangan English Medium School's Astronomy Club, Pune, January 5, 2014.

24. *Searches for life in the universe*, a lecture to the students of D.Y. Patil International School, Mumbai at IUCAA, Pune, January 17, 2014.

25. *Does science education in India help in the development of scientific temper?*, Nehru Centre, Mumbai, January 18, 2014.

26. *Bhaskaracharya dwitiya* (Bhaskaracharya II) (in Marathi), Annasaheb Bendale College, Jalgaon, January 19, 2014.

27. *Vidnyan ani jyotish, vastu shastra, andhashradha* (Science and astrology, vastu shastra, superstitions) (in Marathi), Swastishree Co-op. Housing Society Ltd., Pune, February 1, 2014.

28. *Search for extraterrestrial life in the universe*, D.D. Kosambi Festival of Ideas 2014, Goa, February 6, 2014.

29. *Vishwaparichay* (How well do we know our universe?) (in Marathi), S.B.E.S. College of Science, Aurangabad, February 16, 2014.

30. *Ganitachi vividhrangi rupe* (The many sided aspects of mathematics) (in Marathi), Swami Ramanand Teerth Marathwada Institute of Socio-Economic Research and National Integration, Aurangabad, February 17, 2014.

31. *Are we alone in the universe?*, 22nd Dr. Nayudamma Memorial Lecture, Tenali, March 1, 2014.

32. *96th Convocation Address*, Banaras Hindu University, Varanasi, March 27, 2014.

33. *How well do we know our universe?*, Banaras Hindu University, Varanasi, March 28, 2014.

A.N. Ramaprakash

1. *Blind men and the elephant: Evening talk*, Sastra Sahitya Prishad, Chalakudy, Kerala, July 12, 2013.

2. *Ideas of spacetime in our Universe: CNN GHS*, Cherpu, Kerala, August 08, 2013.

Tarun Souradeep

1. *Pratham galpa (First story)*, Presidency University visiting students, IUCAA, February 24, 2014.

Kandaswamy Subramanian

1. *Galaxies and cosmology* (2 lectures), Fergusson College, Pune, July 2013.

2. *Magnetizing the universe*, Frontiers in Physics, Fergusson College, Pune, January 2014.

POPULAR ARTICLES

Naresh Dadhich

The *Indian plural mind*, Economic and Political Weekly, **XLIX**, 39, 2014.

J.V. Narlikar

1. *Cosmic perspectives on human existence*, Summerhill, **XVIII**, 1, 2, 2013.
2. *Science and speculation: 60 of separation*, The Asian Age, April 10, 2013.
3. *Mobile maniacs*, The Asian Age, May 8, 2013.
4. *Those little chaps called quasars*, The Asian Age, June 5, 2013.
5. *Oh! The joy of mind-benders*, The Asian Age, July 3, 2013.
6. *Bradman's nightmare*, The Asian Age, July 18, 2013.
7. *Gravity of life*, The Asian Age, July 31, 2013.
8. *Twisting facts into a black hole*, The Asian Age, August 28, 2013.
9. *The sum of gender bias in haloed halls*, The Asian Age, September 25, 2013.
10. *The Bose is Higgs boson*, The Asian Age, October 23, 2013.
11. *Take up one idea*, The Asian Age, November 20, 2013.
12. *It's all in the label!*, The Asian Age, December 18, 2013.
13. *A universe made for man*, The Asian Age, January 15, 2014.
14. *The importance of dissent*, The Asian Age, February 12, 2014.
15. *Bhaskara's questions to Lilavati still dazzle*, The Asian Age, March 13, 2014.
16. *Seeta and Geeta: Ek kavya vidamban* (in Hindi) [Seeta and Geeta: A poetic parody], Deep Bhava, 232, 2013.
17. *British bobbyche bavankashi anubhav* (in Marathi) [Factual experiences of the British policeman], Saptarang, Sakal, April 7, 2013.
18. *Juna te sona; pan vachvaycha kasa?* (in Marathi) [Old is gold: But how to preserve it?], Saptarang, Sakal, May 5, 2013.
19. *Cambridge vidyapeeth: Avaghe 800 vayaman!* (in Marathi) [Cambridge University: Aged only 800 years!], Saptarang, Sakal, June 2, 2013.
20. *Me chautha sinha* (in Marathi) [4th lion - An open letter to political leader], Bharatiya Grahak Chalval, 294, 2013.
21. *Kisse Cambridgechya Tripos pariksheche* (in Marathi) [Stories of the Cambridge tripos], Saptarang, Sakal, July 7, 2013.
22. *Savarkaranchi vidnyan-nishtha* (in Marathi) [Savarkar's devotion to Science], Swa. Veer Savarkar 'Sahasdin' Smaranika, 31, 2013.

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23. *Aryabhatta' navhe; 'Aryabhata'!* (in Marathi) [Not 'Aryabhatta'; 'Aryabhata'!], Saptarang, Sakal, August 4, 2013.

24. *Jar gurutvakarshan nasta tar …!* (in Marathi) [If there were no gravity…!], Saptarang, Sakal, September 1, 2013.

25. *Vidnyanatala sangarsh: Prastapith virudha navodit* (in Marathi) [Conflict in science between the established and the new], Saptarang, Sakal, October 6 , 2013.

26. *Sapadla re sapadla!* (in Marathi) [Found at last!], Saptarang, Sakal, November 3, 2013.

27. *Ase vinod, ase vaidnyanik* (in Marathi) [Human and the scientist], Saptarang, Sakal, December 1, 2013.

28. *Kalpanepekshai vastav adabhut* (in Marathi) [Reality is more wonderful than imagination], Chaturang, Loksatta, December 14, 2013.

29. *Vaidnyanik drushtikonachi garaj* (in Marathi) [The need for the scientific outlook], Vanarai Special Issue 2013, 65, 2013.

30. *Parkiya jeevshrustishi sanvad sadhata yeil ka?* (in Marathi) [Can we contact alien cultures?], Saptarang, Sakal, January 5, 2014.

31. *Bhaskaracharya dwitiya* (in Marathi) [Bhaskaracharya II], Saptarang, Sakal, February 2, 2014.

32. *Kahi pauranik kisse ... asehi!* (in Marathi) [Some stories from our ancient puranas], Saptarang, Sakal, March 2, 2014.

Tarun Sourdeep

Eunstein's predictions are coming true, Mumbai Mid-day, March 19, 2014.

Radio/TV Programmes

J.V. Narlikar

Participated in a symposium “Bahujan Hitay” organized by All India Radio, Mumbai, July 23, 2013.

Research

Sk. Saiyad Ali

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 ($z \leq 6$).We have calculated the expected signal and foregrounds for the upgraded Ooty Radio Telescope (ORT), which operates at frequency $\nu_0 = 326.5$ MHz, which corresponds to redshift z = 3.35. Assuming that the visibilities contain only the HI signal and system noise, we have shown that a 3σ detection of the HI signal ($\sim 0.54mJy$) is possible at angular scales $11'$ to 3° with $\approx$ 1000 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 and K. P. Harikrishnan

On the transition to hyperchaos and the structure of hyperchaotic attractors

Using a recently proposed algorithmic scheme for correlation dimension analysis of hyperchaotic attractors, we have studied two well-known hyperchaotic flows and two standard time delayed hyperchaotic systems in detail numerically. We have shown that at the transition to hyperchaos, the nature of the scaling region changes suddenly and the attractor displays two scaling regions for embedding dimension $M \geq 4$. We have argued that it is an indication of a strong clustering tendency of the underlying attractor in the hyperchaotic phase. Because of this sudden qualitative change in the scaling region, the transition to hyperchaos can be easily identified using the discontinuous changes in the dimension (D2) at the transition point. We have shown this explicitely for the two time delayed systems. Further support for our results is provided by computing the spectrum of Lyapunov Exponents (LE) of the hyperchaotic attractor in all cases. Our numerical results imply that the structure of a hyperchaotic attractor is topologically different from that of a chaotic attractor with inherent dual scales, at least for the two general classes of hyperchaotic systems we have analysed here. This work has been done in collaboration with R. Misra.

Bijan Kumar Bagchi

Tracking down localized modes in PT-symmetric Hamiltonians under the influence of a competing non-linearity

The relevance of parity and time reversal (PT)-symmetric structures in optical systems is known for sometime with the correspondence existing between the Schroedinger equation and the paraxial equation of diffraction, where the time parameter represents the propagating distance and the refractive index acts as the complex potential. In this work, we have systematically analyzed a normalized form of the non-linear Schroedinger system with two new families of PT-symmetric potentials in the presence of competing non-linearities. We have generated a class of localized eigenmodes, and carry out a linear stability analysis on the solutions. In particular, we have found an interesting feature of bifurcation charaterized by the parameter of perturbative growth rate passing through zero, where a transition to imaginary eigenvalues occurs.This work has been done in collaboration with Subhrajit Modak and Prasanta K. Panigrahi.

Tanwi Bandyopadhyay

Thermodynamic study of non-linear electrodynamics in loop quantum cosmology

We have discussed the Maxwells electrodynamics in non-linear forms in FRW universe. The energy density and pressure for non-linear electrodynamics have been written in the electro-magnetic universe. The Einsteins field equations for flat FRW model in loop quantum cosmology have been considered if the universe is filled with the matter and electromagnetic field. We have separately assumed the magnetic universe and electric universe. The interaction between matter and magnetic field have been considered in one section and for some particular form of interaction term, we have found the solutions of magnetic field and the energy density of matter. We have also considered the interaction

between the matter and electric field and another form of interaction term has been chosen to solve the field equations. The validity of generalized second law of thermodynamics has been investigated on apparent and event horizons using Gibbs law and the first law of thermodynamics for magnetic and electric universe separately.This work has been done in collaboration with Ujjal Debnath.

Vasudha Bhatnagar

Exploratory analysis of light curves: A case-study in astronomy data understanding

Data acquisition in biology and astronomy has seen unprecedented growth in volume since the turn of the century. It will not be an exaggeration to state that the needs of these two sciences are pushing computer science research to new frontiers. The focus of this work is astronomy, which since inception of Virtual Observatory and commissioning of massive sky surveys is gasping for knowledge in data deluge. Astro-computing, which subsumes Astro-informatics, is a recent multidisciplinary field of research with computer science and astronomy at the core. In this article, we dwell upon the opportunities and challenges for machine learning and data mining research thrown open by this emerging discipline. We have presented a case study of an ongoing work on exploratory analysis of unclassified light curves. Though scientific analysis and interpretation of the results of the study are pending, the exercise demonstrates the merit of customized exploratory approach for study. The approach is general and can be applied to light curves obtained from any survey. Owing to the gargantuan scale of astronomy data processing requirements, we have discussed scalability of the proposed method. This work has been done in collaboration with Aditi Mittal, Abhishek Santra, and Dhriti Khanna.

Shuvendu Chakraborty

Observational study of higher dimensional magnetic universe in non-linear electrodynamics

We have considered the flat FRW model of the universe in (n + 2)-dimensions filled with the dark matter and the magnetic field. We have presented the Hubble parameter in terms of the observable parameters Ω_{m0} and H_0 with the redshift z and the other parameters like $B_0, \omega, \mu_0, \delta, n, w_m$. The nature of magnetic field B, deceleration parameter q and Om diagnostic have also been analyzed for accelerating expansion of the universe. From Stern data set (12 points), we have obtained the bounds of the arbitrary parameters by minimizing the χ^2 test. The best fit values of the parameters are obtained by 66%, 90% and 99% confidence levels. Now to find the bounds of the parameters (B_0, ω) and to draw the statistical confidence contour, we have fixed four parameters μ_0, δ, n, w_m. Here, the parameter n determines the higher dimensions and we perform comparative study between three cases: 4D (n = 2), 5D (n = 3) and 6D (n = 4) respectively. Next, due to joint analysis with BAO observation, we have also obtained the bounds of the parameters (B_0, ω) by fixing other parameters μ_0, δ, n, w_m for 4D, 5D and 6D. The best fit of distance modulus for this theoretical model and the Supernova Type Ia Union2 sample are drawn for different dimensions.This work has been done in collaboration with C. Ranjit and U. Debnath.

Dynamical system analysis for anisotropic universe in Brans-Dicke theory

We have studied the Brans-Dicke (BD) cosmology in anisotropic models. We have presented three dimensional dynamical system describing the evolution of anisotropic models containing perfect fluid and BD scalar field with self-interacting potential. The relevant equations have been transformed into the dynamical system. The critical points and the corresponding eigen values have been found in radiation, dust, dark energy, ΛCDM and phantom phases of the universe. The nature and the stability around the critical points have also been investigate.This work has been done in collaboration with J. Bharra and U. Debnath.

Subenoy Chakraborty

Will there be again a transition from acceleration to deceleration in course of the dark energy evolution of the universe?

We have considered the evolution of interactive dark fluids in the background of homogeneous and isotropic FRW model of the universe. The dark fluids consist of a warm dark matter and dark energy, and both are described as perfect fluid with barotropic equation of state. The dark species interact non-gravitationally through an additional

term in the energy conservation equations. An autonomous system is formed in the energy density spaces and fixed points have been analyzed. A general expression for the deceleration parameter has been obtained and it is possible to have more than one zero of the deceleration parameter. Finally, vanishing of the deceleration parameter has been examined with some examples. This work has been done in collaboration with Supriya Pan.

Do recent observations favour a cosmological event horizon: A thermodynamical prescription?

Recent observational evidence supports an accelerating expansion of the Universe during the present epoch. It is commonly incorporated into standard cosmology by the introduction of exotic matter (which violates the strong energy condition) known as dark energy (DE). As an event horizon exists for an accelerating universe, there has been much work on universal thermodynamics, i.e., thermodynamics of a universe bounded by an apparent or event horizon. Recently, thermodynamical equilibrium has been examined for both types of horizons. In this work, we have shown that universal thermodynamics with an event horizon is favoured by DE from the point of view of an equilibrium thermodynamical prescription. This work has been done in collaboration with Subhajit Saha.

Ramesh Chandra

Multi-wavelength diagnostics of the precursor and main phases of an M1.8 flare on 22 April 2011

We have studied the temporal, spatial and spectral evolution of the M1.8 flare, which occurred in the active region 11195 (S17E31) on April 22, 2011 and explored the underlying physical processes during the precursor phase and their relation to the main phase. The study of the source morphology using the composite images in 131 A° wavelength observed by the Solar Dynamics Observatory/Atmospheric Imaging Assembly and 6 - 14 keV [from the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI)] has revealed a multi-loop system that destabilized systematically during the precursor and main phases. In contrast, hard X-ray emission (20 - 50 keV) has been absent during the precursor phase, appearing only from the onset of the impulsive phase in the form of foot-points of emitting loops. This study also has revealed the heated loop-top prior to the loop emission, although no accompanying foot-point sources were observed during the precursor phase. We have estimated the flare plasma parameters, namely temperature (T), emission measure (EM), power-law index (γ) and photon turn-over energy (ε_{to}), and found them to be varying in the ranges 12.4 - 23.4 MK, 0.0003 - 0.6 $10^{49} cm^{-3}$, 5 - 9 and 14 - 18 keV, respectively, by forward fitting RHESSI spectral observations. The energy released in the precursor phase has been thermal and constituted $\approx$ 1 per cent of the total energy released during the flare. The study of morphological evolution of the filament in conjunction with synthesized T and EM maps has been carried out, which reveals (a) partial filament eruption prior to the onset of the precursor emission, and (b) heated dense plasma over the polarity inversion line and in the vicinity of the slowly rising filament during the precursor phase. Based on the implications from multi-wavelength observations, we have proposed a scheme to unify the energy release during the precursor and main phase emissions in which the precursor phase emission has been originated via conduction front that resulted due to the partial filament eruption. Next, the heated leftover S-shaped filament underwent slow-rise and heating due to magnetic reconnection and finally erupted to produce emission during the impulsive and gradual phases. This work has been carried out jointly with the collaborators A.K. Awasti, R. Jain, et al.

Solar energetic particle events during the rise phases of solar cycles 23 and 24

We have presented a comparative study of the properties of coronal mass ejections (CMEs) and flares associated with the solar energetic particle (SEP) events in the rising phases of solar cycles (SC) 23 (1996 - 1998) (22 events) and 24 (2009 - 2011) (20 events), which are associated with type II radio bursts. Based on the SEP intensity, we have divided the events into three categories, i.e., weak (intensity $<$ 1 pfu), minor (1 pfu $<$ intensity $<$ 10 pfu) and major (intensity $\geq$ 10 pfu) events. We have used the GOES data for the minor and major SEP events and SOHO/ERNE data for the weak SEP event. We have examined the correlation of SEP intensity with flare size and CME properties. We have found that most of the major SEP events are associated with halo or partial halo CMEs originating close to the centre of the

sun and western-hemisphere. The fraction of halo CMEs in SC 24 is larger than that in the SC 23. For the minor SEP events, one event in SC 23 and one event in SC 24 have widths $<$ 120°, and all other events are associated with halo or partial halo CMEs as in the case of major SEP events. In case of weak SEP events, majority (more than 60%) of the events are associated with CME width $<$ 120°. For both the SCs, the average CMEs speeds are similar. For major SEP events, average CME speeds are higher in comparison to minor and weak events. The SEP event intensity and GOES X-ray flare size are poorly correlated. During the rise phase of solar cycles 23 and 24, we have found north-south asymmetry in the SEP event source locations: in cycle 23, most sources are located in the south, whereas during cycle 24, most sources are located in the north. This result is consistent with the asymmetry found with sunspot area and intense flares.This work has been carried out jointly with the collaborators, W. Uddin, A.K. Srivastava, et al.

Suresh Chandra

Importance of collisional rates for anomalous absorption in H_2CC molecule

Formaldehyde (H_2CO) is the first organic molecule identified in a number of galactic and extragalactic sources. It has been identified through its transition 1_{10} - 1_{11} at 4.829 GHz in absorption. Later on, this transition of formaldehyde has been found as showing anomalous absorption in the direction of four dark nebulae. Anomalous absorption is an unusual phenomenon. Structure of H_2CC is very similar to that of H_2CO and H_2CS. Both H_2CO and H_2CS have already been identified in a number of cosmic objects. Since cosmic abundance of carbon is 20 times larger than that of sulfur, we have proposed that H_2CC may be identified in cool cosmic objects through its transition 1_{10} - 1_{11} at 4.85 GHz. Keeping in view of the similarity of energy levels of H_2CC with H_2CO, in the present investigation we have performed calculations for three sets of collisional rates for rotational transitions in ortho-H_2CO due to collisions with (i) He atom, (ii) ortho-H_2 (J = 1), and (iii) para-H_2 (J = 0). All the three sets of calculations have showed the anomalous absorption of 1_{10} - 1_{11}transition of H_2CC. However, the anomalous absorption of 2_{11} - 2_{12} transition has been found to be weak.This work has been done in collaboraion with M.K. Sharma and Monika Sharma.

Small Fe bearing ring molecules of possible astrophysical interest: Molecular properties and rotational spectra

A number of small, cyclic molecules containing several carbon atoms in their ring structure has been identified in different astrophysical environments. It is the aim of this work to study important molecular properties of such hetero-cyclic species bearing an iron atom, which is one of the most abundant cosmic elements. Quantum theoretical calculations based on a density functional approach have been employed to investigate physical properties of six small cyclic carbon and hydrocarbon molecules containing iron as a hetero atom, viz, $F_eC_2H_n$ and $F_eC_3H_n$ (n = 0, 2, 4). The full geometry optimisation at the chosen level of electronic theory (B3LYP/6-31G(d)) including vibrational anharmonic and non-rigidity, has furnished values for the rotational constants of these species to an expected accuracy of about one per cent. We have presented structural, electronic, vibrational and rotational molecular properties including line frequencies, line strengths, and transitions probabilities. These results may be helpful for identifying these molecules in future laboratory experiments in view of tentative astronomical observations.This work has been done in collaboration with Ch. Chang, A.B.C. Patzer and W.H. Kegel.

Asis Kumar Chattopadhyay

Clustering large number of extragalactic spectra of galaxies and quasars through canopies

Clustering is a technique used to place data elements into related groups without advance knowledge of the group definitions, and clustering algorithms are attractive for the task of identification in coherent groups for existing data sets. It is a common problem in several streams of science, although the purpose and implication may vary. Depending on the assumption and nature of the data, several techniques have been developed by scientists for clustering, in order to make proper analysis of data. Such data sets are generally multivariate in nature. The common problem is to find a suitable representation of the multivariate data.

Cluster analysis is the distribution of objects into different groups or more precisely, the partitioning of a data set into subsets (clusters), so that the data in subsets share some common trait according to some distance measure. Unlike classification, in clustering one has to first decide the optimum number of clusters and then assign the objects into different clusters. Solution to such problems for a large number of high dimensional data points is quite complicated, and most of the existing algorithms will not perform properly. In this work, a new clustering technique applicable to large data set has been used to cluster the spectra of 702,248 galaxies and quasars having 1,540 points in wavelength range imposed by the instrument. The proposed technique has successfully discovered five clusters from this 702,248 $\times$ 1,540 data matrix.This work has been carried out jointly with Tuli De and Didier Fraix Burnet.

Asis Chattopadhyay and Tanuka Chattopadhyay

Performance comparison of clustering techniques on the basis of galaxy data

Clustering and classification of different astronomical objects have become one of the most important areas in the field of Astro-statistics. The basic objective of cluster analysis is related to segmentation of a collection of objects into a (unknown) number of clusters, such that objects in the same cluster are more closely related than those assigned to different clusters. Cluster analysis is also used to study, on the basis of descriptive statistics, whether each group consists of objects with significantly different properties. There are many methods available for clustering, which may be broadly categorized under supervised and unsupervised learning. In case of supervised learning, there are some input variables (predictors) and also some output variables (responses). But in case of unsupervised learning, only predictors are under consideration in the absence of responses. Under both the above mentioned categories, for clustering and classification, several methods have been developed on the basis of the underlying nature of data sets. However, there is no well known criteria to compare the performances of different techniques. The present work makes an attempt to compare the applicability of some of the clustering techniques on the basis of two astronomical data sets, one Gaussian and the other non-Gaussian. Clustering have been done with respect to all the variables as well as significant components. A post-classification technique is used as a supervised learning to justify the robustness of the variety of unsupervised methods used in this purpose. Finally, the similarity of clusters obtained from different methods is viewed in terms of astro-physical properties of the objects grouped in different clusters. This work has been jointly carried out with Tuli De.

Surajit Chattopadhyay

Dependence of the Brans-Dicke parameter on scalar field

The present work reports a study on the dimensionless parameter ω in Brans-Dicke theory. Based on a particular choice of scale factor a, we have investigated the signature flip of the deceleration parameter q to see whether the transition from decelerated to accelerated expansion of the universe is achievable under this choice of scale factor. Restrictions on the parameters obtained for this choice of scale factor have been subsequently used for discussing the Brans-Dicke parameter for two choices of scalar fields ϕ. Moreover, analytical solutions for the Brans-Dicke parameter without any assumption about the scalar field have been obtained from the modified field equations through the choice of scale factor under consideration. Viable models have been obtained by comparing the results with observations. The present study is motivated by the work of Ganguly and Banerjee (*Int. J. Mod. Phys. D* **18** 445 (2009)), who have shown that by expressing the dimensionless parameter ω in the Brans-Dicke theory as a function of the scalar field ϕ in a certain way, the process of expansion of the universe can be shown to make a transition from an initial phase of deceleration to a phase of acceleration, manifested through a signature flip of the deceleration parameter q at some instant of cosmic time. In the first phase, we have chosen the scale factor $a(t)$ in such a way that the deceleration parameter q, based on it, evolves into a negative value from a positive one as a function of time. Based on our chosen scale factor, the Hubble parameter H has been determined as a function of time. In the second phase, using Brans-Dicke theory, we have derived an expression

of the parameter ω as a function of the scalar field ϕ. Here, we have considered three models: (i) We have chosen scalar field ϕ as a function of a as $\phi(a) = \phi_1 \exp[\alpha a]$. Using the modified field equations for Brans-Dicke theory and with this choice of scalar field, we have obtained a quadratic equation of α and for both of its roots, we have observed the behaviours of ϕ against the scale factor a and the time t. (ii) We have considered the scalar field as $\phi(a) = \phi_0 \exp[\beta a]$. Proceeding in the same manner as in the previous model, we have obtained a quadratic equation of β and for both of the roots, we have observed the behaviours of ϕ against the scale factor a and the time t. We have observed similar behaviour as of the first model. (iii) We have not made any assumption regarding the scalar field ϕ. Using the chosen scale factor in the field equations, we have obtained the scalar field and Brans-Dicke parameter as functions of t. This work has been carried out in collaboration with Sudipto Roy.

In another work, we have considered the Ricci dark energy model, proposed by Gao, et. al, we have observed a quintom-like behaviour of the equation of state parameter, and a transition from matter dominated to dark energy density has been observed through fraction density evolution. The statefinder parameters reveal that the model interpolates between dust and ΛCDM phases of the universe.

Raghavendra Chaubey

An interacting two-fluid scenario for dark energy in anisotropic cosmological model

The open anisotropic cosmological model of the early Universe has been considered. We have studied the evolution of the dark energy parameter within anisotropic Bianchi type V cosmological model filled with barotropic fluid and dark energy. The solutions have been obtained for power law and exponential forms of the expansion parameter. (They correspond to constant deceleration parameter in general relativity.) For large time, the models tend asymptotically to an isotropic Friedmann Robertson - Walker cosmological model under certain conditions.This work has been done in collaboration with T. Singh.

A new class of Bianchi cosmological models in f(R,T) gravity

The new class of cosmological model of the early Universe has been considered with f(R,T) modified theories of gravity. The exact solutions to the corresponding field equations have been obtained in quadrature form, and the cosmological parameters have been discussed in detail. We have also discussed the well-known astrophysical phenomena, namely the Hubble parameter H(z), luminosity distance (d_L) and distance modulus $\mu(z)$ with redshift.This work has been done in collaboration with A.K. Shukla.

Partha Chowdhury

Periodicities in the X-ray emission from the solar corona

We have studied the time series of full disk integrated soft and hard X-ray emission from the solar corona during 2004 January to 2008 December, covering the entire descending phase of solar cycle 23 from a global point of view. We have employed the daily X-ray index derived from 1 s cadence X-ray observations from the Si and CZT detectors of the Solar X-ray Spectrometer mission in seven different energy bands ranging between 6 and 56 keV. X-ray data in the energy bands 67, 710, 1020, and 425 keV from the Si detector have been considered, while 1020, 2030, and 3056 keV high energy observations have been taken from the CZT detector. The daily time series is subjected to power spectrum analysis after appropriate correction for noise. The Lomb - Scargle periodogram technique has shown prominent periods of $\sim$ 13.5 days, $\sim$ 27 days, and a near-Rieger period of $\sim$81 days and $\sim$1.24 yr in all energy bands. In addition to this, other periods like $\sim$ 31, $\sim$ 48, $\sim$ 57, $\sim$ 76, $\sim$ 96, $\sim$ 130, $\sim$ 227, *and* $\sim$ 303 days are also detected in different energy bands. We have discussed our results in the light of previous observations and existing numerical models.This work has been done in collaboration with R. Jain and A. Awasthi.

Himadri Sekhar Das

Polarimetric studies of Comet C/2009 P1 (Garradd)

We have studied the optical imaging polarimetric observations of comet C/2009 P1(Garradd) at three different phase angles, e.g., 28.2°, 28.1° and 21.6°. The observations were carried out using IUCAA Faint Object Spectrograph and Camera mounted on Cassegrain focus of the 2m Telescope of IUCAA Girawali Observatory (IGO), in R_{comet}, R photometric bands, on 21 and 22 March 2012 and ARIES Imaging Polarimeter mounted on Cassegrain focus of the 1.04 m Sampurnanand Telescope of ARIES, Nainital in R photometric band, on 23 May 2012. We have shown the presence of a jet activity in the rotational gradient treated image of comet Garradd at phase angle 28.1°. These jets are mainly oriented towards the Sun and extended up to $\sim$ 5,100 km from the cometary photocentre. The anti-solar extension of jet seems to be fainter, which is extended up to $\sim$ 1800 km. It is found that the comet Garradd shows negative polarization at phase angle 21.6°. The degree of polarization derived for Garradd is in good agreement with other comets at nearly similar phase angles, e.g., comets 67P/Churyumov-Gerasimenko, 22P/Kopff, 1P/Halley, C/1990 K1 (Levy), 4P/Faye, and C/1995 O1 (Hale-Bopp) at phase angle $\sim$ 28°, and 47P/Ashbrook-Jackson at phase angle $\sim$ 21.6°, respectively. It is also found that the degree of polarization of dusty coma of comet Garradd at phase angle $\sim$ 28° is high, but not as high as in the case of comet Hale-Bopp. This work has been done in collaboration with B.J. Medhi, S. Wolf, G. Bertrang, P. Deb Roy and A. Chakraborty.

Sudipta Das

An interacting model of dark energy in Brans-Dicke theory

It has been shown that in non-minimally coupled Brans-Dicke theory containing a self-interacting potential, a suitable conformal transformation can automatically give rise to an interaction between the normal matter and the Brans-Dicke scalar field. Considering the scalar field in the Einstein frame as the quintessence matter, it has been shown that such a non-minimal coupling between the matter and the scalar field can give rise to a late time accelerated expansion for the universe preceded by a decelerated expansion for very high values of the Brans-Dicke parameter ω. We have also studied the observational constraints on the model parameters considering the Hubble and Supernova data.This work has been done in collaboration with Abdulla Al Mamon.

Ujjal Debnath

Constraining red-shift parametrization parameters of dark energy: Loop quantum gravity as background

It has been assumed that the FRW universe filled with dark matter (perfect fluid with negligible pressure) along with dark energy in LQC gravity, where three parameterizations have been proposed for the variations of EOS parameter $\omega(z)$ and they are linear, CPL and JBP parameterizations. From Stern, Stern+BAO and Stern+BAO+CMB joint data analysis, we have obtained the bounds of the arbitrary parameters ω_0 and ω_1 and by minimizing the test. The best fit values and bounds of the parameters are obtained by 66%, 90% and 99% confidence levels for Stern data analysis, Stern+BAO joint data analysis and Stern+BAO+CMB joint data analysis for linear, CPL and JBP models. The distance modulus $\mu(z)$ against redshift z has been investigated for our predicted theoretical model of the three models for the best fit values of the parameters and the observed SNe Ia Union2 data sample and it has been shown that our predicted theoretical three models permitted the observational data sets. This work has been done in collaboration with Ritabrata Biswas.

Roles of different forms of scale factor in non-linear electrodynamics for accelerating universe

We have assumed the modified Lagrangian of non-linear electrodynamics for accelerated universe. The energy density and pressure for non-linear electromagnetic theory have been considered in terms of both electric and magnetic fields. The Einstein's field equations have been considered in FRW universe for Horava-Lifshitz gravity. Since we have been considering the non-linear form of Lagrangian for accelerating universe, so four forms of scale factors like logamediate, intermediate, emergent and power law forms have been chosen in our investi-

gation. For every expansion, the natures of electric field and magnetic field have been analyzed. The electric and magnetic fields increase for logamediate, intermediate and emergent expansion and decrease in power law expansion.This work has been done in collaboration with Sayani Maity.

Jishnu Dey and Mira Dey

Strange star equation of state fits the refined mass measurement of 12 pulsars and predicts their radii

There are three categories of stars whose masses have been found accurately in recent times: (1) two for which Shapiro delay is used, which is possible due to GR light bending as the partner is heavy: PSR J1614 - 2230 and PSR J1903+0327 (2) six eclipsing stars for which numerical Roche Lobe geometry is, used and (3) three stars for which spectroscopic methods are used, and in fact, for these three, the mass and radii both are estimated. Motivated by large colon (N_c) expansion, using a modified Richardson potential, along with density dependent quark masses, thereby allowing chiral symmetry restoration, we get compact strange stars fitting all the observed masses. This work has been done in collaboration with T. Gangopadhyay, S. Ray and Xiang-Dong Li.

Broja Gopal Dutta

Phase lag and quasi-periodic oscillation frequency correlation in galactic black hole candidate XTE J1550-564

The complex behaviour of Fourier phase lags associated to Quasi-Periodic Oscillations (QPOs) is one of the most significant observational effects of galactic black hole sources. This temporal property can diagnose the dynamics of accretion flow around the black holes. We have analyzed RXTE/PCA data of the black hole source XTE J1550-564 for the 1998 outburst. We have found smooth decrease of the time lag(s) with time in the rising phase and in the declining phase, it increases with time. We have concluded that this variation could be due to the movement of the Comptonizing region itself. We have also found that evolution of phase/time lag is correlated with the QPO frequency. This behaviour suggests a common evolution scenario of the black hole transient XTE J1550-564 through its outburst.

Sunandan Gangopadhyay

Analytic study of properties of holographic superconductors away from the probe limit

Based on the Sturm-Liouville eigenvalue approach, we have analytically investigated the properties of holographic superconductors in the background of pure Einstein and Gauss-Bonnet gravity, taking into account the back reaction of the spacetime. Higher value of the back reaction parameter results in a harder condensation to form in both cases. The analytical results obtained have been found to be in good agreement with the existing numerical results.

Path integral action of a particle in a magnetic field in the non-commutative plane and the Aharonov - Bohm effect

The formulation of non-commutative quantum mechanics as a quantum system represented in the space of Hilbert-Schmidt operators is used to systematically derive, using the standard time slicing procedure, the path integral action for a particle moving in the non-commutative plane and in the presence of a magnetic field and an arbitrary potential. Using this action, the equation of motion and the ground state energy for the partcle have been obtained explicitly. The Aharonov-Bohm phase has been derived using a variety of methods and several dualities between this system and other commutative and non-commutative systems have been demonstrated. Finally, the equivalence of the path integral formulation with the non-commutative Schrödinger equation has also been established. This work has been done in collaboration with Fredrik G. Scholtz.

Sushant G. Ghosh

Higher dimensional non-Kerr black hole and energy extraction

We have investigated the properties of the horizons and ergosphere in a rotating higher dimensional (HD) deformed Kerr-like black hole. We have also explicitly brought out the effect of deformation parameter ε, and the extra dimension on the efficiency of the Penrose process of energy extraction from a black hole. It is interesting to see that the ergosphere size is sensitive to the de-

formation parameter ε as well as spacetime dimensions D. This gives rise to a much richer structure of the ergosphere in a HD non-Kerr black hole, thereby making the Penrose process more efficient compared with that of the four-dimensional Kerr black hole.This work has been done in collaboration with Pankaj Sheoram.

Gravitational collapse of null dust in f(R) gravity

We have found exact non-static null-dust solutions in metric f(R) gravity, imposed by the constant scalar curvature, which describes the gravitational collapse of null dust in (anti-)de Sitter [(A)dS] higher-dimensional (HD) background. The situation where a null-dust injects into the initially HD-(A)dS spacetime leads to a naked singularity from gravitational collapse in HD-f(R) gravity, violating cosmic censorship conjecture. Further, we have found exact null-dust solutions to constant curvature imposed non-Abelian f(R)-Yang-Mills gauge theory by employing the Wu-Yang ansatz in four dimensions. This generates an identical geometry as one would expect for charge null-dust in the Abelian f(R) Maxwell theory, i.e., precisely the charged-Vaidya-(A)dS corresponding to Yang-Mills gauge charge. The four-dimensional charged null-dust solutions in the f(R) Maxwell theory have also been, separately derived. This work has been done in collaboration with Sunil D. Maharaj.

Sarbari Guha

Dissipative cylindrical collapse of charged anisotropic fluid

We have studied 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. The Einstein-Maxwell field equations were calculated, and using the Darmois junction conditions, matched 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 have been analyzed. From the dynamical equations, the effect of charge and dissipative quantities over the cylindrical collapse have been studied. Finally, the solutions for the collapsing matter have been presented, which are valid during the later stages of collapse and discussed the significance from a physical stand point.This work has been done in collaboration with Ranajoy Banerji.

Gravity in five-dimensional warped product spacetimes with time-dependent warp factor.

Sarbari Guha and her student have considered gravity in a 5-dimensional warped product spacetime with a time-dependent warp factor and time-dependent extra dimension. The brane world has been described by a spatially flat FRW-type metric. The five dimensional field equations have been constructed and solved, and the status of the energy conditions have been examined. In the high energy regime, the bulk has been assumed to be sourced by a scalar field. The effective cosmological constant of the 4-dimensional universe is a variable quantity monitored by the time-dependent warp factor, and leads to a geometric interpretation of dynamical dark energy. This work has been carried out in collaboration with Pinaki Bhattacharya.

Sk. Monowar Hossein and Md. Mehedi Kalam

Anisotropic quintessence stars

We have proposed a relativistic model for quintessance stars with the combination of an anisotropic pressure field, corresponding to normal matter and a quintessence dark energy field having a characteristic parameter ω_q such that $-1 < \omega_q < -1/3$. We have discussed various physical features of the model and shown that the model satisfies all the regularity conditions and can provide stable equilibrium configurations.This work has been done in collaboration with another Associate Farook Rahaman and S. Molla.

Geodesic study of a charged black hole

The behaviour of the time like and null geodesics of charged E. Ayon-Beato and A. Garcia (ABG) black hole have been investigated. For circular and radial geodesics, we have investigated all the possible motions by plotting the effective potentials for different parameters. In conclusion, we have shown that there is no phenomenon of super-radiance in this case. This work has been done in collaboration with Nur Farhad.

Ngangbam Ibohal

New tortoise coordinate transformation and Hawking's radiation de Sitter space

Hawking's radiation effect of Klein-Gordon equation, Dirac particles and Maxwell's electromagnetic fields in the non-stationary rotating de Sitter cosmological spacetime has been investigated by using a new method of generalized tortoise coordinate transformation. It has been found that the new transformation produces constant additional terms in the expressions of the surface gravities and the Hawking's temperatures. If the constant terms have been set to zero, then the surface gravities and Hawking's temperatures are equal to those obtained from the old generalized tortoise coordinate transformations. This shows that the new transformations are more reasonable. The Fermionic spectrum of Dirac particles displays a new spin-rotation coupling effect.

This work has been done in collaboration with T. Ibungochouba.

Geometry of embedded black holes

Two black holes may merge to form an embedded one. However, the metric tensors of the two black holes cannot simply add to obtain an embedded black hole. It has been discussed that every embedded black hole is expressible in Kerr-Schild ansatz.

K. Indulekha

Role of gas dynamical friction in the evolution of embedded stellar clusters:

Two puzzles associated with open clusters have attracted a lot of attention to their formation, with densities and velocity dispersions that are not too different from those of the star forming regions in the Galaxy, given that the observed Star Formation Efficiencies (SFE) are low, and the mass segregation observed/inferred in some of them, at ages significantly less than the dynamical relaxation times in them. Gas dynamical friction has been considered before as a mechanism for contracting embedded stellar clusters, by dissipating their energy. This would locally raise the SFE, which might then allow bound clusters to form. Noticing that dynamical friction is inherently capable of producing mass segregation, since here, the dissipation rate is proportional to the mass of the body experiencing the force, we have explored further, some of the details and implications of such a scenario, vis-a-vis observations. Making analytical approximations, we have obtained a boundary value for the density of a star forming clump of given mass, such that, stellar clusters born in clumps which have densities higher than this, could emerge bound after gas loss, and for a clump of given mass and density, we have found a critical mass such that, subcondensations with larger masses than this could suffer significant segregation within the clump.

Naseer Bhat Iqbal

The peculiar velocity and temperature profile of galaxy clusters

Dynamical parameters like average velocity dispersion and temperature profile of galaxy clusters are determined using a quasi-equilibrium thermodynamic theory. The calculated velocity dispersion results from theory and simulations show a good agreement with the velocity dispersion results of (Abdullah, et al. 2011). An Adaptive Mesh Refinement (AMR), Grid based hybrid code have been used to carry out the simulations. Our results indicate that the average velocity dispersion profile of 20 Abell galaxy clusters falls in the range of 500 - 1000 km/s and their temperature profile is of the order of 107 to 108 K calculated on the basis of kinetic theory. The data shows a significant contribution of gravitating particles clustering together in the vicinity of cluster centre, and beyond a certain region this velocity dies out, and gets dominated by the Hubbles flow due to which all the galaxy clusters in an expanding universe participate in Hubbles expansion. This work has been done in collaboration with T. Masood.

S.N.A. Jaaffrey

The linkages of anthropogenic emissions and meteorology in the rapid increase of particulate matter at a foothill city in the Arawali range of India.

The city of Udaipur (24.58 N, 73.68 E) in the province of Rajasthan in the western part of India has a special significance as it is surrounded by the Arawali mountain ranges on one side and desert on the other side. It is located around the foothills of the rocky Arawali range. The changing pattern

in particulate matter (PM 2.5 and PM 10) during the past three years indicates an alarming increasing trend, posing a threat to its environment and tourism sector, which regulates its economy, distribution of particulate matter is found to be governed by the meteorology, and changes the trend. The level of PM 10, which was already above the threshold level in 2010, further increased in 2012. The trend is found to be rapid during the months of October and November, where an increase by 37% is observed in 3 years. The level of PM 2.5, which is the most hazardous for respiratory system diseases, has now started to cross the ambient air quality standards set by the World Health Organization. The impact is significant during winter when the inversion layer is down due to colder temperature, and foreign tourists are a peak giving rise an increased morbidity rate. The linkages of local weather with an anthropognically induced trend and long range transport of pollutants have been outlined. This work has been done in collaboration with Ravi Yadav and Q. Beig.

Detection of a variable QPO at $\sim$ 41mHz in the Be/X-ray transient pulsar 4U 0115+634

We have detected quasi-periodic oscillation (QPO) at $\sim$ 41 mHz in the transient high-mass Be/X-ray binary pulsar 4U 0115+634 using data from the Rossi X-Ray Timing Explorer (RXTE) observatory. The observations used in the present work were carried out during X-ray outbursts in 1999 March - April, 2004 September - October and 2008 March - April. This frequency of the newly detected QPO was found to vary in 2746 mHz range. This $\sim$ 41 mHz QPO was detected in four of the 36 pointed RXTE Proportional Counter Array (PCA) observations during 1999 outburst where as during 2004 and 2008 outbursts, it was detected in four and three times out of 33 and 26 observations, respectively. Though QPOs at $\sim$ 2 mHz and $\sim$ 62 mHz were reported earlier, the $\sim$ 41 mHz QPO and its first harmonic were detected for the first time in this pulsar. There are three RXTE/PCA observations where multiple QPOs were detected in the power-density spectrum of 4U 0115+634. Simultaneous presence of multiple QPOs is rarely seen in accretion-powered X-ray pulsars. Spectral analysis of all the pointed RXTE/PCA observations revealed that the 3 - 30 keV energy spectrum was well described by Negative and Positive power law with EXponential (NPEX) cut-off continuum model along with interstellar absorption and cyclotron absorption components. During the three X-ray outbursts, however, no systematic variation in any of the spectral parameters other than the earlier reported anti-correlation between cyclotron absorption energy and luminosity was seen. Presence of any systematic variation of QPO frequency and rms of QPO with source flux were also investigated yielding negative results. This work has been done in collaboration with Moti R. Duggair, Gaurava K. Jaiswal and Sachindra Naik.

Deepak Jain and Sanjay Jhingan

Exploring scalar field dynamics with Gaussian processes

The origin of the accelerated expansion of the Universe remains an unsolved mystery in cosmology. We have considered a spatially flat Friedmann-Robertson-Walker (FRW) Universe with non-relativistic matter and a single scalar field contributing to the energy density of the Universe. Properties of this scalar field, like potential, kinetic energy, equation of state, etc. are reconstructed from Supernovae and BAO data using Gaussian processes. We have also reconstructed energy conditions and kinematic variables of expansion, such as the jerk and the slow roll parameter. We have found that the reconstructed scalar field variables and the kinematic quantities have been consistent with a flat Lambda-CDM Universe. Further, it has been found that the null energy condition is satisfied for the redshift range of the Supernovae data considered, but the strong energy condition is violated.This work has been done in collaboration with Remya Nair.

Observational cosmology and the cosmic distance-duality relation

We have studied the validity of cosmic distance duality relation between angular diameter and luminosity distances. To test this duality relation, we have used the latest Union2 Supernovae Type Ia (SNe Ia) data for estimating the luminosity distance. The estimation of angular diameter distance comes from the samples of galaxy clusters (real and mock) and FRIIb radio galaxies. We have parameterized the distance duality relation as a function of redshift in four different ways and found that the mock data set, which assumes a spheri-

cal isothermal β model for the galaxy clusters, which does not accommodate the distance duality relation, while the real data set which assumes elliptical β model does. This work has been done in collaboration with Remya Nair.

Md. Mehedi Kalam

Central density dependent anisotropic compact stars

Stars can be treated as self-gravitating fluid. In this connection, we have proposed a model for an anisotropic star under the relativistic framework of Krori-Barua spacetime (Krori 1975). It is shown that the solutions are regular and singularity free. The uniqueness of the model is that the interior physical properties of the star solely depend on the central density of the matter distribution. This work has been done in collaboration with F. Rahaman, Sk. M. Hossein and S. Ray.

Nagendra Kumar

Kelvin-Helmholtz instability in dusty plasma with sheared magnetic field

Nagendra Kumar and collaborators (Vinod Kumar and Anil Kumar) have studied the Kelvin-Helmholtz instability in dusty plasma with sheared magnetic field and density. They have considered a multi-component plasma, consisting of electrons, ions, and dust particles in a plane slab geometry, where equilibrium density and magnetic shear vary in x-direction. The electrostatic potential and velocity of positive ions depend on the x. Dispersion relation has been obtained and solved numerically. The instability has been discussed by computing the growth rate for different set of values of various parameters. It has been found that growth rate of the instability decreases with the increase in frequency ratio parameter and shear parameter.

Suresh Kumar

Cosmology with hybrid expansion law: Scalar field reconstruction of cosmic history and observational constraints

We have considered a simple form of expansion history of Universe referred to as the hybrid expansion law: A product of power-law and exponential type of functions. The ansatz by construction mimics the power-law and de Sitter cosmologies as special cases but also provides an elegant description of the transition from deceleration to cosmic acceleration. We have constructed potentials for quintessence, phantom and tachyon fields, which can give rise to the hybrid expansion law in general relativity, and investigated observational constraints on the model with hybrid expansion law applied to late time acceleration as well as to early Universe a la nucleosynthesis. This work has been done in collaboration with Ozgur Akarsu, R. Myrzakulov, M. Sami and Lixin Xu.

Anisotropic model of a dark energy dominated Universe with hybrid expansion law

The dynamics of the Universe has been studied in the framework of a spatially homogeneous Bianchi-V spacetime filled with a perfect fluid composed of non-interacting matter and dynamical dark energy components. We have determined the Bianchi-V spacetime by considering a hybrid expansion law (HEL) for the average scale factor that yields power-law and exponential law cosmologies in its special cases. In the HEL cosmology, the Universe exhibits a transition from deceleration to acceleration. We have found that the HEL Universe in the framework of Bianchi-V spacetime is anisotropic at early stages of evolution and becomes isotropic at late times. The dynamic dark energy in this Universe does not show a departure from the usual cosmological constant at later times.

V.C. Kuriakose

Scalar filed evolution and area spectrum for Lovelock-AdS black holes

We have studied the modes of evolution of massless scalar fields in the asymptotically AdS spacetime surrounding maximally symmetric black holes of large and intermediate size in the Lovelock model. It has been observed that all modes are purely damped at higher orders. Also, the rate of damping is seen to be independent of order at higher dimensions. The asymptotic form of these frequencies for the case of large black holes has been found analytically and finally, the area spectrum for such black holes has also been found from these asymptotic modes. This work has been done in collaboration with C.B. Prasobh.

Thermodynamics and quasinormal modes of Park black hole in Horava gravity.

We have studied the quasinormal modes of the massless scalar field of Park black hole in the Hořava gravity using the third-order WKB approximation method and found that the black hole has been stable against these perturbations. We have compared and discussed the results with that of Schwarzschild-de Sitter black hole. Thermodynamic properties of Park black hole have been investigated and the thermodynamic behaviour of upper mass bound has also been studied. This work has been done in collaboration with Jishnu Suresh.

Badam Singh Kushvah

Lyapunov characteristic exponents in the generalized photo-gravitational Chermnykh-like problem with power law profile

The stochastic properties of the dynamical system can be explained well after computing the spectrum of Lyapunov Characteristic Exponents (LCEs) of the system. The LCEs provide characterization of dynamical behaviour and measure average rate of divergence or convergence of neighbouring trajectories in the phase space. We have studied the dynamical behaviour of generalized photo-gravitational Chermnykh-like problem with power law profile with the help of LCEs. We have considered bigger primary as a radiating body and smaller one as an oblate spheroid with the addition of a disk moving in a circular orbit around common centre of mass of the primaries. It has been found that the trajectories are chaotic in nature due to the positive LCEs. The effect of radiation pressure, oblateness and the disk on LCEs of the system have been analyzed. It has been observed that these factors play a significant role to characterize the chaotic nature of the trajectory. This work has been done in collaboration with Ram Kishor.

Linear stability and resonances in the generalized photo gravitational Chermnykh-like problem with a disc

Today, the main concerns in dynamical systems are stability, dynamical processes and the factors causing them, which determine their past evolution. We have presented a systematic study of the linear stability of triangular equilibrium points, under the influence of perturbations in the form of radiation pressure, oblateness and the presence of a disc. We have seen that points are stable for mass ratios $0 < \mu < \mu^c = 0.04185$, which is greater than Rouths value $\mu^c = 0.03852$. Further, analysis is performed under three main resonance cases and it is observed that the stability region expands the presence of the disc. Perturbed mass ratios $\mu^\kappa, \kappa = 1, 2, 3$, for these three resonances are obtained under appropriate approximations. Finally, the effect of these perturbations has been analysed with the help of the results obtained, and it is noted that they influence the motion of an infinitesimal mass significantly, but the effect of the disc dominates over radiation pressure and oblateness. This theory is applicable not only to four cases examined earlier by researchers but also to a generalized case, as in the present model. The results are limited to a radially symmetric regular disc but can be extended in future. This work has been done in collaboration with Ram Kishor.

Manzoor A. Malik

Distribution function for the system of galaxies for any ratio of gravitational potential to kinetic energies

We have evaluated distribution function for the system of galaxies clustering gravitationally in an expanding universe on the basis of statistical mechanics. We have extended our previous work to incorporate the effect of any ratio of gravitational potential to kinetic energies, and determined the cosmological many-body partition function, inclusive of higher order terms and calculated all thermodynamic quantities and the distribution function from it. We have found that our new results are consistant with the previous ones, particularly in the large $\bar{N}$ (average number of galaxies) limit. We have also investigated the effect on clustering parameter b and found that our new results are in very good agreement with the previous ones in the small b limit. We have found that for large b, the departure from the original distribution function is greater. We have also observed that the effect of softening on the distribution function is consistant with our previous work. This work has been done in collaboration with Farooq Ahmad and Hameeda Mir.

Lee Yang theory for cosmological many body problem

We have studied the phase transition in a gravitating system by analysing grand canonical partition function as a function of complex fugacity. We have extended the Yang-Lee theory to study phase transitions in the gravitational galaxy clustering of galaxies having a variety of masses. This generalizes our previous work based on the same theory for the single-component system to a multi-component system. We have found that galaxy clustering is sensitive to masses and number densities of individual galaxies at early stages, while at later stages collective behaviour of the particles is more pronounced. This validates our earlier work obtained from different considerations. This work has been done in collaboration with Mohammad S. Khan.

Soma Mandal

Alternating lags of QPO harmonics: A generic model and its application to the 67 millihertz QPO of GRS 1915+105

A generic model for alternating lags in QPO harmonics has been presented, where variations in the photon spectrum are caused by oscillations in two parameters that characterize the spectrum. It has been further assumed that variations in one of the parameters is linearly driven by variations in the other after a time delay t_d. It has been shown that alternating lags will be observed for a range of t_d values. A phenomenological model based on this generic one has been developed, which can explain the amplitude and phase lag variation with energy of the fundamental and the next three harmonics of the 67 mHz QPO observed in GRS 1915+105. The phenomenological model also predicts the variation of the Bicoherence phase with energy, which can be checked by further analysis of the observational data. This work has been done in collaboration with Ranjeev Mishra.

The kilo-second variability of X-ray sources in nearby galaxies

Chandra observations of 17 nearby galaxies have been analysed, and 166 bright sources with X-ray counts > 100, have been chosen for temporal analysis. Fractional root mean square variability amplitudes are estimated for lightcurves binned at $\sim$ 4 ksec and of length $\sim$ 40 ksec. While there have been nine ultra-luminous X-ray sources (ULXs) with unabsorbed luminosity (in 0.3 - 8.0 keV band) $L > 10^{39}$ ergs^{-1} in the sample for which the fractional r.m.s. variability is constrained to be $< 10\%$, only two of them show variability. One of the variable ULXs exhibits a secular transition and has a ultra-soft spectrum with temperature ~ 0.3 keV, while the other is a rapidly varying source in NGC 0628, which has been previously compared to the Galactic micro-quasar GRS 1915+105. These results seem to indicate that ULXs are typically not highly variable in ksec time-scales, except for some ultra-soft ones. Among the relatively low luminosity sources ($L \sim 10^{38}$ erg s^{-1}) we have found five of them to be variable. Apart from an earlier known source in NGC 1569, we have identified a source in NGC 2403, which exhibits persistent high amplitude fluctuations. The variability of the sources in general, do not seem to be correlated with hardness, which indicates that they may not be due to variations in any absorbing material, but instead, could reflect inner accretion disk instabilities.This work has been done in collaboration with Ranjeev Mishra and Gulab C. Dewangan.

Soumen Mondal

The relativistic equation of state in accretion and wind flows.

We have derived 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) has been 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 the 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 and the sound speed a_s have been 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. The main ad-

vantage 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 application revels that shocks in accretion flows become unlikely and except for the region very nearby the compact object, the EOS remains non-relativistic. We therefore, conclude that the new form of EOS will be helpful to verify many conventional ideas in many astrophysical problems. This work has been done in collaboration with Prasad Basu.

The origin of the most probable 3:2 twin-peak quasi-periodic oscillations (QPOs) frequency ratio in the micro-quasars

We have noticed that within a few gravitational radii, where the X-ray emission originates, the perturbations in the accretion disk may excite high frequency quasi-periodic oscillations (QPOs). The vertical and the radial disk oscillations frequencies due to the perturbation exhibit a 3:2 twin-peak ratio, which is most commonly detected in the X-ray fluxes in many Galactic micro-quasars. The high frequency QPOs happen most likely if the oscillations occur very close to the centre. We have further noticed that the perturbations originate in the neighbourhood of the shock transition or from a discontinuity in the disk, and could be the possible mechanism to excite the high frequency QPOs. The shocks are more probable in the X-ray emission region and may form very close to the horizon particularly, when the black hole spin is very high. Studying the shock locations as a function of the black hole spin in a fully general relativistic inviscid transonic accretion flow, we have calculated the disk oscillation frequencies due to the perturbation and their ratios. Further, from the spin dependence, we have estimated the 'most probable spin interval' in the micro-quasars by considering the $1/M$ scaling hypothesis in high frequency QPOs. Finally, we have found the spin (a) interval, which lies for XTE 1550-564, at $a \sim$ (0.89 - 0.99), for the GRO 1655-40, at $a \sim$ (0.96 - 0.99) and for the GRS 1915+105, at $a \sim$ (0.74 - 0.999). The uncertainty in mass analysis corresponds to the above spin intervals. This work has been done in collaboration with C.S. Choi.

Hemwati Nandan

Gravitating dyons in Vaidya geometry

Gravitating monopoles and dyons in Einstein-Yang-Mills (EYM) or Einstein-Yang-Mills-Higgs (EYMH) systems have been extensively studied for various curved spacetimes, including those of black holes. We have constructed dyonic solutions of the EYMH theory in Vaidya spacetime using a set of generalized Julia-Zee ansatz for the fields. It has been found that the dyonic charge is static in nature and it does not contribute to the energy of the null dust. This work has been done in collaboration with B.V. Tripathi, H. Dehnan and K.D. Purohit.

Shear dynamics in higher dimensional FLRW cosmology

We have studied the shear dynamics of higher dimensional FLRW cosmology by considering a non-perfect fluid, which exerts different pressure in the normal and extra dimensions. We have generalized the definition of shear tensor for higher dimensional spacetime and proved it to be consistent with the evolution equation for shear tensor obtained from the Ricci identities. The evolution of shear tensor has been investigated numerically. The role of extra dimensions and other parameters involved in shear dynamics has also been discussed in detail. We have observed that with the increase in anisotropy parameter, time of decay of shear increases, while with increase in number of extra dimensions, shear tends to decay early. This work has been done in collaboration with I. Pahwa and U.D. Goswami.

P.N. Pandita

Critical behaviour of a relativistic Bose gas

We have shown that the thermodynamic behaviour of relativistic ideal Bose gas, recently studied numerically by Grether, et al., can be obtained analytically. Using the analytical results, we have obtained the critical behaviour of the relativistic Bose gas exactly for all the regimes. We have shown that these analytical results reduce to those of Grether, et al. in different regimes of the Bose gas. Furthermore, we have also obtained an analytically closed form expression for the energy density for the Bose gas that is valid in all regimes.

Beam polarization effects in the radiative production of lightest neutralinos in e^+e^- collisions in supersymmetric grand unified models.

We have studied the production of the lightest neutralinos in the process $e^+e^- \to \chi^0 1 \chi^0 1 \gamma$ in supersymmetric, grand unified models for the International Linear Collider energies with longitudinally polarized beams. We have considered cases where the standard model gauge group is unified into the grand unified gauge groups SU(5) or SO(10). We have carried out a comprehensive study of this process in the SU(5) and SO(10) grand unified theories, which includes the QED radiative corrections. We have compared and contrasted the dependence of the signal cross section on the grand unified gauge group, and on the different representations of the grand unified gauge group, when the electron and positron beams are longitudinally polarized. To assess the feasibility of experimentally observing the radiative production process, we have also considered in detail the background to this process coming from the radiative neutrino production process $e^+e^- \to \nu\bar{\nu}\gamma$ with longitudinally polarized electron and positron beams. In addition, we have also considered the supersymmetric background coming from the radiative production of scalar neutrinos in the process $e^+e^- \to \tilde{\nu}\tilde{\nu}^*\gamma$ with longitudinally polarized beams. The process can be a major background to the radiative production of neutralinos when the scalar neutrinos decay invisibly. This work has been done in collaboration with Monalisa Patra.

Amit Pathak

O VI absorption in the Milky Way along the Large Magellanic Cloud lines of sight

We have used *Far Ultraviolet Spectroscopic Explorer (FUSE)* observations of the Large Magellanic Cloud (LMC) to determine the O VI column densities in the Milky Way (MW) towards 6 LMC lines of sight. The mean column density of O VI in the MW is found to be log N(O VI)=$14.257^{+0.096}_{-0.084}$. The results confirm the patchiness of O VI absorption in the MW, and the column densities are higher or comparable to the LMC. This work has been done in collaboration with Rathin Sarma, Ananta C. Pradhan, Jayant Murthy and Jayanta K. Sarma.

Bikash Chandra Paul

Observational constraints on modified Chaplygin gas from cosmic growth

Cosmological models with modified Chaplygin gas making use of the observational data from cosmic growth have been investigated. The linear growth function for the large scale structures of the universe is considered with modified Chaplygin gas as dark energy. The observational growth data for a given range of redshift from the Wiggle-Z measurements and rms mass fluctuations from Ly-alpha measurements are employed to analyze numerically cosmological models and the observational constraints imposed on the EoS parameters of the MCG are determined. The observational data of Hubble parameter with redshift z is also considered. The Wang-Steinhardt ansatz for growth index and growth function f have been considered for the numerical analysis. The best-fit values of the equation of state parameters obtained here are employed to study the growth function, growth index and equation of state variations with redshift. Observational constraints obtained in the case of GCG are compared with that of MCG. It has been noted that MCG satisfactorily accommodates an accelerating phase followed by a matter dominated phase of the universe. This work has been done in collaboration with P. Thakur.

Relativistic charged star solutions in higher dimensions

A class of relativistic solutions of the Einstein-Maxwell (EM) equations for a charged static fluid sphere in higher dimensions has been obtained. The physical 3-space (t = constant) considered here possesses spheroidal geometry described by Vaidya-Tikekar metric. The interior solution of the Einstein-Maxwell equations for a charged static fluid sphere for a given electric field in this case is obtained in higher dimensions. The solution is used to obtain an exact relativistic model for a charged compact object, which is used for a qualitative analysis of the physical aspects of stellar models. The validity of both strong energy (SEC) and weak energy conditions (WEC) for a specific configuration and compactness factor has been explored for different compact objects. It is noted that in four dimensions, there exists a range of values of compactness factor, for which SEC and WEC is found

to violate. However, in five dimensions SEC and WEC have obeyed inside the star. The upper limit of the electric field is found to depend on dimensions of extra space.This work has been done in collaboration with P.K. Chattopadhyay and Rumi Deb.

Ninan Sajeeth Philip

Spectral variability of IRAS 18325-5926 and constraints on the geometry of the scattering medium

We have analyzed Suzaku and XMM-Newton data of the highly variable Seyfert 2, IRAS 18325-5926. The spectra of the source are well modeled as a primary component described as an absorbed power law and a secondary power law component, which is consistent with being scattered emission from an on-axis extended highly ionized medium. We have shown that while the primary component varies on a wide range of time scales from $10^4 - 10^8$ s, the scattered emission is variable only on time scales longer than 10^5 s. This implies that the extent of the scattering medium is greater than 10^{16} cm. The ratio of the scattered to primary flux (~ 0.03) implies a column density for the scattering medium to be $\sim 10^{23} cm^{(-2)}$. We argue that for such a medium to be highly ionized, it must be located less than 10^{17} cm from the X-ray source. Thus, we have localized the position and extent of scattering region to be $\sim$ a few $\times 10^{16}$ cm, with an average particle density of $\sim 10^6 cm^{-3}$. We have considered the physical interpretation of these results, and aside we have confirmed the presence of a broad iron line emission in both the XMM-Newton and Suzaku observations.This work has been done in collaboration with Shruti Tripathi, R. Misra, G.C. Dewangan, Jittu Cheeran and Sheelu Abraham.

Anirudh Pradhan

Two fluid atmosphere from decelerating to accelerating Friedmann-Robertson-Walker dark energy models

Evolution of dark energy parameter within the scope of a spatially homogeneous and isotropic Friedmann-Robertson-Walker model filled with perfect fluid and dark energy components has been studied by generating recent results. The two sources are claimed to interact minimally, so that their energy momentum tensors are conserved separately. The concept of time dependent deceleration parameter with some suitable assumption yields an average scale factor. For $0 < n \leq 1$, this generates a class of accelerating models, while for n $>$ 1, the models of universe exhibit phase transition from early decelerating phase to present accelerating phase, which is supported by results from recent astrophysical observations. It is observed that the transition redshift for our derived model with $q_0 = -0.73$ is $\cong 0.32$. This is in good agreement with cosmological observations in literature. Some physical and geometric properties of this model along with physical acceptability of cosmological solutions have been discussed in detail.

Bianchi type-V cosmology in f(R,T) gravity with $\Lambda(T)$

A new class of cosmological models in f(R,T) modified theories of gravity proposed by Harko, et al., where the gravitational Lagrangian is given by an arbitrary function of Ricci scalar R and the trace of the stress-energy tensor T, have been investigated for a specific choice f(R,T) = $f_1(R) + f_2(T)$ by considering time dependent deceleration parameter. The concept of time dependent deceleration parameter (DP) with some proper assumptions yields the average scale factor. For $0 < n \leq 1$, this generates a class of accelerating models, while for n $>$ 1, the models of universe exhibit phase transition from early decelerating phase to present accelerating phase, which is in good agreement with the results from recent astrophysical observations. Our intention is to reconstruct f(R,T) models inspired by this special law for the deceleration parameter in connection with the theories of modified gravity. Here, we have considered the cosmological constant Λ as a function of the trace of the stress energy-momentum tensor, and dub such a model Λ(T) gravity, where we have specified a certain form of Λ(T). Such models may display better uniformity with the cosmological observations. The state-finder diagnostic pair $\{r, s\}$ parameter has been embraced to characterize different phase of the universe. We also have discussed the physical consequences of the derived models. This work has been done in collaboration with N. Ahmed.

Farook Rahaman

Possible existence of wormholes in the galactic halo region

Two observational results, namely, the density profile from simulations performed in the ΛCDM scenario and the observed flat galactic rotation curves, have been taken as input with the aim of showing that the galactic halo possesses some of the characteristics needed to support traversable wormholes. This result should be sufficient to provide an incentive for scientists to seek observational evidence for wormholes in the galactic halo region. This work has been done in collaboration with P.K.F. Kuhfittig, Saibal Ray and Nasarul Islam.

On topological defects and cosmological constant

Einstein introduced cosmological constant in his field equations in an ad hoc manner. Cosmological constant plays the role of vacuum energy of the universe, which is responsible for the accelerating expansion of the universe. To give theoretical support, it remains an elusive goal to modern physicists. We have provided a prescription to obtain cosmological constant from the phase transitions of the early universe when topological defects, namely monopole might have existed. This work has been done in collaboration with B. Raychaudhuri and M. Kalam.

S.R. Rajesh

Time varaibility of viscosity parameter in differentially rotating disc

We have proposed a mechanism to produce fluctuations in the viscosity parameter (α) in differentially rotating discs. We have carried out a non-linear analysis of a general accretion flow, where any perturbation on the background was treated as a passive/slave variable in the sense of dynamical system theory. We have demonstrated a complete physical picture of growth, saturation and final degradation of the perturbation as a result of the non-linear nature of coupled system of equations. The strong dependence of this fluctuation on the radial location in the accretion disc and the base angular momentum distribution have been demonstrated. The growth of fluctuations is shown to have a time scale comparable to the radial drift time and hence, the physical significance is discussed. The fluctuation is found to be a power law in time in the growing phase, and we have briefly discussed its statistical significance. This work has been done in collaboration with Nishant K.Singh.

Shantanu Rastogi

Polycyclic aromatic hydrocarbon molecules in astrophysics

In collaboration with Amit Pathak and Anju Maurya, we have reviewed the results of their various computational models for the understanding of mid-infrared emission features, which have been ubiquitous in almost all types of astrophysical environments. Polycyclic aromatic hydrocarbon (PAH) molecules are responsible for these emission features. Their presence in different environments and related variations in their spectral profiles make them an important tool to understand the physics and chemistry of the interstellar medium. The observed spectrum is generally a composite superposition of all different types of PAHs possible in the region. In the era of space telescopes, the spectral richness of the emission features has enhanced their importance as probe, and also the need to understand the variations with respect to PAH size, type and ionic state. Quantum computational studies of PAHs have proved useful in elucidating the profile variations, and put constraints on the possible types of PAHs in different environments. PAH formation pathways in the circumstellar shells of late type stars point to the possibility of PAHs with vinyl side group. The improvements in emission models on incorporating such PAH derivatives have been discussed. The study of PAHs has also significantly contributed to the problems of diffuse interstellar bands (DIBs), UV extinction, and understanding the chemistry of the formation of complex organics in space.

Spectral modeling near the 1.6 m window for satellite based estimation of CO_2

Measurements of inter-annual CO_2 variability are important inputs for modelling global carbon cycle. Satellite observations play important role in quantification and modelling of CO_2 fluxes in the atmosphere, where observed radiances in narrow spectral channels are used to estimate the trace gas concentration using spectroscopic principles. We

have identified that 1.6 μm spectral window is important for CO_2 detection and they simulate the two CO_2 bands in this region at different spectral resolutions. In order to select the optimum spectral resolution and wavelength positions, suitable for CO_2 estimation from satellite platform, sensitivities of different spectral lines to changes in CO_2 concentration have been studied. Analysis is carried out using a line by line FASCOD radiative transfer model in tropical atmospheric and rural aerosol conditions. The CO_2 concentration is varied from 200 to 1000 ppmv, and spectral resolution is varied from 0.025 nm to 10 nm. It is observed that atmospheric transmittances reduce sharply with increase in CO_2 concentration. With decrease in resolution initially, the sensitivity steeply reduces, but at resolutions lower than 0.15 nm, the sensitivity remains nearly constant. The Continuum Interpolated Band Ratio method is used for inverse concentration retrieval. Based on the study, it has been evaluated that 0.2 nm is the optimum limit for resolution. The study is also of relevance for remote sensing of the atmosphere of Mars. This work has been done in collaboration with Prabhunath Prasad, R.P. Singh and S. Panigrahy.

C.D. Ravikumar

Morphological analysis of early type galaxies from field

Ravikumar C.D. and his collaborators Dhanya Joseph, Preetha A.U. and Nikesh M. have conducted morphological analysis of a sample of early type galaxies from field. Bulge-disc decomposition of the sample observed in near infra-red K band from Two Micron All Sky Survey (2MASS), using a full two-dimensional decomposition algorithm, suggests strong evidence for presence of significant stellar disc in many ellipticals. The bulge and disc scale radii also show strong correlation, like their counterparts in lenticulars and spirals. If confirmed, the finding spurs re-thinking on the longevity of discs in ellipticals.

X-ray point source population in NGC 1399

Ravikumar C.D. along with Aswathy S. and Preetha A.U., has performed the aperture photometry of the optical counter parts of the bright, non-nuclear X-ray sources in the giant elliptical NGC 1399 with an aim to investigate their X-ray to optical association. We have identified 29 X-ray point sources (Lx $\geq$ 1038 erg/sec) in NGC 1399 including five Ultra-Luminous X-ray sources (ULXs). We have found that the X-ray luminosities are anti-correlated with their optical (F475W-F814W) colours, the linear correlation coefficient being - 0.92 at a significance greater than 99.99%. The optical counter parts are definitely multiple sources, and hence, the strong correlation exhibited by X-ray sources suggests the possibility of existence of multiple sources for the production of X-rays also. Otherwise, it will be difficult to observe such a correlation, given the strong variable nature of bright X-ray sources.

Saibal Ray

BTZ black holes inspired by non-commutative geometry

A Banados-Teitelboim-Zanelli (BTZ) black hole has been constructed from an exact solution of the Einstein's field equations in a (2+1) dimensional anti-De Sitter spacetime in the context of non-commutative geometry. The BTZ black hole turns out to have either two horizons, no horizon, or a single horizon corresponding to a minimal mass. Certain thermodynamical properties have been investigated, including Hawking temperature, entropy, and heat capacity. Also, we have discussed the geodesic structure of BTZ black holes for both massless and massive particles. In particular, it has been shown that bound orbits for test particles are possible. This work has been done in collaboration with F. Rahaman, P.K.F. Kuhfittig, B.C. Bhui, M. Rahaman and U.F. Mondal.

Saibal Ray and Anisul Ain Usmani

Oscillatory Universe, dark energy and general relativity

The concept of oscillatory Universe appears to be realistic, and buried in the dynamic dark energy equation of state. We have explored its evolutionary history under the framework of general relativity. We have observed that oscillations do not go unnoticed with such an equation of state and that their effects persist later on in cosmic evolution. The 'classical' general relativity seems to retain the past history of oscillatory Universe in the form of

increasing scale factor, as the classical thermodynamics retains this history in the form of increasing cosmological entropy. This work has been done in collaboration with P.P. Ghosh and U. Mukhopadhyay.

Biplab Raychaudhuri

Sagnac effect in (2+1) dimensional gravitational field

A Sagnac type experiment has been analyzed in the most well-known (2 + 1) dimensional Banados, Teitelboim and Zanelli (BTZ) spacetime and discussed vis-a-vis corresponding results in (3 + 1) dimensional spacetime. The angular velocity of locally non-rotating observer has formally been predicted using Sagnac effect. Occurrence of arbitrarily large Sagnac delay (SD) for geodesic motion has been observed for extreme BTZ black hole universally as its remarkable feature.

Anirban Saha

COW test of the weak equivalence principle: A low-energy window to look into the non-commutative structure of spacetime?

We have constructed the quantum mechanical model of the COW experiment assuming that the underlying spacetime has a granular structure, described by a canonical non-commutative algebra of coordinates. The time-space sector of the algebra is shown to add a mass-dependent contribution to the gravitational acceleration felt by neutron de Brogli waves measured in a COW experiment. This makes time-space non-commutativity a potential candidate for an apparent violation of WEP, even if the ratio of the inertial mass and gravitational mass is a universal constant. The latest experimental result based on COW principle is shown to place an upper-bound several orders of magnitude stronger than the existing one on the time-space non-commutative parameter. We have argued that the evidence of NC structure of spacetime may be found if the COW-type experiment can be repeated with several particle species.

Trace of phase-space non-commutativity in the response of a free particle to linearized gravitational waves

Interaction of linearized gravitational waves with otherwise free particle has been studied quantum mechanically in a non-commutative phase-space to examine whether the particle's response to the gravitational wave gets modified due to spatial and/or momentum non-commutativity. The result shows that momentum non-commutativity introduces a oscillatory noise with a specific frequency determined by the fundamental momentum scale and particle mass. Because of the global nature of the phase-space non-commutativity, such noise will have similar characteristics for all detector sites and thus, will stand out in a data cross-correlation procedure. If detected, this noise will provide evidence of momentum non-commutativity and also an estimation of the relevant non-commutative parameter. This work has been done in collaboration with Sunandan Gangopadhyay and Swarup Saha.

Sanjay Kumar Sahay

Web document clustering and ranking using Tf-Idf based apriori approach.

The dynamic web has increased exponentially over the past few years with more than thousands of documents related to a subject available to the user. Most of the web documents are unstructured and not in an organized manner and hence, users face difficulties to find relevant documents. A more useful and efficient mechanism is combining clustering with ranking, where clustering can group the similar documents in one place and ranking can be applied to each cluster for viewing the top documents at the beginning. Besides the particular clustering algorithm, the different term weighing functions applied to the selected features to represent web document is a main aspect in clustering task. Keeping this approach in mind, we have proposed a new mechanism called Tf-Idf based apriori for clustering the web documents. We have then ranked the documents in each cluster using Tf-Idf and similarity factor of documents based on the user query. This approach will help the users to get all the relevant documents in one place and can restrict the search to some top documents of choice. For experimental purpose, we have taken the Classic3 and Classic4 datasets of Cornell Uni-

versity, having more than 10,000 documents and use gensim tool kit to carry out the work. We have compared our approach with traditional apriori algorithm and found that the approach is giving better results for higher minimum support. The ranking mechanism is also giving a good F-measure of 78%.This work has been done in collaboration with R.K. Roul and Omanwar Rohit Devanand.

Evolution and detection of polymorphic and metamorphic malwares: A survey

We have studied the malwares threat to digital world, its evolution and complexity. Malware can penetrate networks, steal confidential information from computers, bring down servers, can cripple infrastructures, etc. To combat the threat/attack from the malwares, anti-malwares have been developed. The existing anti-malwares are mostly based on the assumption that the malware structure does not change appreciably. But the recent advancement in second generation malwares can create variants and hence, posed a challenge to anti-malwares developers. To combat the threat/attacks from the second generation malwares with low false alarm, we have discussed the various techniques to detect the malwares. This work has been done in collaboration with Ashu Sharma.

Sanjay Baburao Sarwe

Stability analysis in N-dimensional gravitational collapse with equation of state

We have studied the stability of occurrence of black holes and naked singularities that arise as the final states of a complete gravitational collapse of type I matter field in a spherically symmetric N - dimensional spacetime with equation of state $p = k\rho$, $0 \leq k \leq 1$. We have proved that for a regular initial data comprising of pressure (or density) profiles at an initial surface $t = t_i$, from which the collapse evolves, there exists a large class of the velocity functions and classes of solutions of Einstein equations, such that the spacetime evolution goes to a final state, which is either a black hole or a naked singularity. We have used suitable function spaces for regular initial data leading the collapse to a black hole or a naked singularity, and shown that the data forms an open subset of the set of all regular initial data. In this sense, both the outcomes of collapse are stable. These results have been discussed and analyzed in the light of the cosmic censorship hypothesis in black hole physics. This work has been done in collaboration with R.V. Saraykar.

Jets in micro-quasar SS433: Analysis involving acceleration

We have analyzed multi-wavelength observations of the jets of the micro-quasar SS433 vis-á-vis acceleration dependence of Doppler effect. Specifically, we have been only interpreting the spectral shifts as arising due to the acceleration-dependent Doppler effect and found the speed of blue-shifted jet to be $\sim 0.022c$ and that of red-shifted jet to be $\sim 0.29c$. Our results have consequences for the energetics of the prime mover and jets in SS433. This work has been done in collaboration with Sanjay M. Wagh.

Anjan Ananda Sen

Constraining thawing dark energy using galaxy cluster number counts

We have studied the formation of galaxy clusters in the presence of thawing class of scalar field dark energy. We have considered cases where the scalar field has canonical as well as non-canonical kinetic term in its action. Various forms for the potential of the scalar field, e.g., linear, quadratic, inverse quadratic, exponential as well as Pseudo-Nambu-Goldstone-Boson (PNGB) type have also been considered. Moreover, we have investigated the situation where dark energy is homogeneous as well as takes part in virialization process. We have used the Sheth-Tormen formalism while calculating the number density of galaxy clusters. Our results show that cluster number density for different dark energy models have significant deviation from the corresponding value for the ΛCDM case. The deviation is more for higher redshifts. Moreover the tachyon type scalar field with linear potential has the highest deviation from the ΛCDM case. For the total cluster number counts, different dark energy models can have substantial deviation from ΛCDM and this deviation is most significant around z $\sim$ 0.5 for all the models we have considered. We have also constrained thawing class of models using the presently available data for number counts of massive X-ray clusters. The results show that the current cluster data is not suitable enough for con-

straining potentials for the thawing scalar fields as well as for other cosmological parameters. But one can get significant constraint for the parameter σ_8 and a lower bound on Ω_{m0}. This work has been done in collaboration with N. Chandrachani Devi and T. Roy Choudhury.

Cosmology with axionic-quintessence coupled with dark matter

We have studied the possibility of explaining the late time acceleration with an axion field, which is coupled with the dark matter sector of the energy budget of the Universe. The axion field arises from the Ramond-Ramond sector of the Type-IIB string theory. We have studied the background evolution of the Universe as well as the growth of the matter perturbation in the linear regime, and subsequently, used the observational data from Sn-Ia, BAO, measurements of the Hubble parameter as well as the observational data for the growth of the matter perturbation to constrain our model. Our results show that coupled axion models are allowed to have larger deviation from cosmological constant by the present observational data. This work has been done in collaboration with Sumit Kumar and Sudhakar Panda.

Ashoke Kumar Sen

Rosin's law and size distribution of particles in regolith like samples: An analysis

Rosin's law describes the cumulative distribution of matter obtained by crushing the solid materials into dusts. Although this distribution has been found to agree with lunar regolith samples, it should be tested with sufficient amount of experimental data from regolith like samples (like asteroids) of known particle size distribution, so that it can be used for various remote sensing applications. We have tested the applicability of Rosin's distribution by comparing with experimental data for 28 different regolith like samples reported by other authors. Such samples represent regolith layers, which are present on the surfaces of various comets. Finally, a simple interpretation of the Rosin numbers (k and n) was given in relation with the physical parameters of the samples. This work has been done in collaboration with his student D. Deb.

Anand Sengupta

Predicting the spread of alligator weed (Alternantheraphiloxeroides) in Wular Lake, India: A mathematical approach

Alligator weed (Alternantheraphiloxeroides) is an amphibious weed invading worldwide. It was reported very recently from Wular Lake, a Ramsar site in India. The weed forms isolated floating islands of variable sizes in this lake. Monitoring of the weed for 4 years reveals that the total number of patches increased from 6 in 2008 to 82 in 2011 with total area of all patches increasing from 41.3 m^2 in 2008 to 831 m^2 in 2011. We did predictive modeling with four years data using a variable growth rate equation, to estimate the spread rate of the weed assuming the entire lake area available for spread. Our model suggests that this weed may potentially cover entire lake in 1319 years from 2008. The robustness of the mathematical model was also determined and validated using data from the first three years and it was in coherence with the previous model. We do caution, the predictive spread model of A. philoxeroides presented here, which has a strong bearing to the uncertainties of climate change, nutrient loading and competition effects. The study warrants an urgent need for rapid action involving manual removal before it actually assumes bigger dimensions in the lake and the region as more than ten thousand households completely depend on the resources of Wular Lake, India. This work has been done in collaboration with A. Masoodi, F.A. Khan and G.P. Sharma

Searching for gravitational waves from binary coalescence

We have described the implementation of a search for gravitational waves from compact binary coalescences in LIGO and Virgo data. This all-sky, all-time, multi-detector search for binary coalescence has been used to search data taken in recent LIGO and Virgo runs. The search is built around a matched filter analysis of the data, augmented by numerous signal consistency tests designed to distinguish artifacts of non-Gaussian detector noise from potential detections. We have demonstrated the search performance using Gaussian noise and data from the fifth LIGO science run and demonstrated that the signal consistency tests are capable of mitigating the effect of non-Gaussian noise and

providing a sensitivity comparable to that achieved in Gaussian noise.This work has been done in collaboration with S. Babak, R. Biswas, et al..

Ranjan Sharma

Relativistic stellar model admitting a quadratic equation of state

Ranjan Sharma, in collaboration with B. S. Ratanpal, has developed an anisotropic stellar model, which has been shown to be regular and physically reasonable. To make the Einstein's field equations mathematically tractable, they have utilized the Finch and Skea ansatz for the metric potential g_{rr}, which has a geometric interpretation for the associated background spacetime. Motivated by the fact that at the interior of compact stellar objects, local anisotropy of pressure might be caused by a large variety of physical phenomena, and the authors have incorporated a general anisotropic parameter in the stress-energy tensor and generated a new class of solutions. Based on physical grounds, appropriate bounds on the model parameters have been prescribed and stability of the configuration has been analyzed. The authors have also generated an approximated equation of state (EOS) corresponding to the material composition of the fluid sphere, which has been found to be quadratic in nature. In cosmological models driven by dark matter/energy, a quadratic EOS has often been shown to be relevant for the description of specific evolutionary stages of the universe. However, in the high density regime of compact astrophysical objects, what kind of matter can support an exotic quadratic-type EOS remains is a matter of further investigation.

Spacetime inhomogeneity and gravitational collapse

We have reported a general framework to investigate the impacts of inhomogeneity and local anisotropy on the non-adiabatic collapse of a star emanating energy in the form of radial heat flux. We have presented a new class of solutions, describing the collapse of a shear-free stellar body endowed with anisotropic stresses. The reported model is a generalization of the Banerjee, *et al.* model, which describes the collapse of a homogeneous distribution of isotropic fluid. An in-depth analysis of the physical processes corresponding to the two different background spacetimes reveals that within the framework of classical GR, gross features of the evolving systems remain unaffected by the induction of inhomogeneous perturbations and anisotropic pressure in FRW geometry. This work has been done in collaboration with Ramesh Tikekar.

Harinder Pal Singh

Chemical and structural analyisis of the Large Magellani Cloud using the fundamental mode RR Lyrae stars.

We have done a careful and detailed light-curve analysis of publicly available I-band data on fundamental mode RR Lyrae (RRab) stars of the Large Magellanic Cloud (LMC), obtained by the Optical Gravitational Lensing Experiment phase-III project. Using the Fourier parameters of 13,095 RRab stars, metallicities and absolute magnitudes of individual stars have been obtained. The representation of stars on the Period-Fourier parameter plane showed the existence of three significant metallicity groups with mean metallicities as $1.20 \pm 0.12, 1.57 \pm 0.10$ *and* 1.89 ± 0.09 *dex*. The corresponding absolute magnitudes of these three groups were obtained as 0.70 ± 0.08, 0.59 ± 0.06 *and* 0.49 ± 0.08 *mag*, respectively. Distribution of these three groups as a function of vertical $\mid z \mid$ distance indicates that the formation of the LMC disc predates the formation of the inner halo. Issue of the existence of a metallicity gradient as a function of galacto-centric distance has also been addressed. Approximating the structure of the LMC disc as a triaxial ellipsoid, the inclination angle relative to the plane of the sky and the position angle of the line of nodes have been estimated as 24.20 deg and 176.01 deg respectively. The axes ratios and the eccentricity have also been determined using the principal axis transformation method. This work has been done in collaboration with Sukanta Deb.

Visibilty-graph analysis of the solar wind

We have analyzed in situ measurements of the solar wind velocity obtained by the Advanced Composition Explorer (ACE) and the Helios spacecraft during the years 1998 - 2012 and 1975-1983, respectively. The data mainly belong to solar cycles 23 (1996-2008) and 21 (1976-1986). We have used the directed horizontal-visibility-graph (DHVg) al-

gorithm and estimated a graph functional, namely, the degree distance (D), which is defined using the Kullback-Leibler divergence (KLD) to understand the time irreversibility of solar wind time-series. This degree-distance irreversibility parameter has been estimated for these time-series at different phases of the solar activity cycle. The irreversibility parameter was first established for known dynamical data and was then applied to solar wind velocity time-series. It has been observed that irreversibility in solar wind velocity fluctuations show a similar behaviour at 0.3 AU (Helios data) and 1 AU (ACE data). Moreover, the fluctuations change over the phases of the activity cycle. This work has been done in collaboration with Vinita Suyal and A. Prasad.

K. Yugindro Singh

Vaidya black hole in non-stationary de Sitter space: Hawking's temperature

We have presented a class of non-stationary solutions of Einstein's field equations describing embedded Vaidya-de Sitter black holes with a cosmological variable function $\Lambda(u)$. The Vaidya-de Sitter black hole has been interpreted as the radiating Vaidya black hole embedded into the non-stationary de Sitter space with variable $\Lambda(u)$. The energy-momentum tensor of the Vaidya-de Sitter black hole is expressed as the sum of the energy-momentum tensors of the Vaidya null fluid and that of the non-stationary de Sitter field, and satisfies the energy conservation law. Further, we have studied the energy conditions (like weak, strong and dominant conditions) for the energy-momentum tensor. There is the violation of the strong energy condition, due to the negative pressure, thus, leading to a repulsive gravitational force of the matter field associated with $\Lambda(u)$ in the spacetime. It is found that the time-like vector field for an observer in the Vaidya-de Sitter space is expanding, accelerating, shearing and non-rotating. It has been shown that the spacetime geometry of non-stationary Vaidya-de Sitter solution with variable $\Lambda(u)$ is Petrov type D in the classification of space-times. The Vaidya-de Sitter black hole radiating with a thermal temperature to be proportional to the surface gravity, and entropy also to be proportional to the area of the cosmological black hole horizon. This work has been done in collaboration with the Ph.D. student Ngangbam Ishwarchandra.

Evolution of QSOs: The optical luminosity function

Using the data of the 2 Degree Field (2dF) QSO Redshift Survey (2QZ) and the associated 6 Degree Field (6dF) QSO Redshift Survey (6QZ) of the Anglo-Australian Telescope, we have carried out a study of the optical luminosity function of Quasi Stellar Objects (QSOs) to understand the evolutionary scenario. Different models for the QSO evolution have been studied. The two-power law model of the optical luminosity function with second order polynomial evolution is found to fit best the observed QSO optical luminosity function. We have also determined an improved evolutionary model, which fits better than the second order polynomial evolution model. The best fit parameters for the observed optical luminosity function have been determined using the Levenberg-Marquardt algorithm of non-linear least square fit for a flat universe. The observed slope of the log $N - m$ curve, i.e., 1.10 ± 0.01 reveals that there are more QSOs at larger distances (or look back times) than there have been locally which, in turn, indicates that the QSOs are evolving. The observed value of $< V/Vmax >$ is found to be greater than 0.5 for different values of the cosmological constant, which also hints strong evolution of the QSOs. This work has been done in collaboration with I. Ablu. Meitei.

Parijat Thakur

Investigating close-in exoplanets through transit observations

We have been investigating the transit timing variations (TTVs) in extra-solar planetary systems, which could imply the existence of additional unseen planets. The thirty seven transit light curves of the TrES-3 planetary system have been analyzed. In this way, we have determined the orbital parameters of TrES-3 system, and also investigated possible transit timing variations (TTVs). It has been found that a model with an additional planet fits the observational data better than the null TTV model. In addition to this, we have also concluded that the additional planet with order of hundred Earth-mass located near but not exactly at 1:2 exterior resonance to exoplanet TrES-

3b could be a possibility. To further investigate this possibility, the future high-precision observations for the TrES-3 system will be very important. This work has been done in collaboration with Ing-Guey Jiang, Li-chin Yeh, et al.

Pranjal Trivedi

Primordial magnetic field limits from CMB trispectrum: Scalar modes and Planck constraints

Cosmic magnetic fields have been observed to be coherent on large scales and could have a primordial origin. Non-Gaussian signals in the cosmic microwave background (CMB) are generated by primordial magnetic fields as the magnetic stresses and temperature anisotropy they induce depend quadratically on the magnetic field. We have computed the CMB scalar trispectrum on large angular scales, for nearly scale-invariant magnetic fields, sourced via the Sachs-Wolfe effect. The trispectra induced by magnetic energy density and by magnetic scalar anisotropic stress are found to have typical magnitudes of approximately 10^{-29} and 10^{-19}, respectively. The scalar anisotropic stress trispectrum has also been calculated in the flat-sky approximation, which yields a similar result. Observational limits on CMB non-Gaussianity from the *Planck* mission data allow us to set upper limits of $B_0 \lesssim 0.6$ nG on the present value of the primordial cosmic magnetic field. Considering the inflationary magnetic curvature, mode in the trispectrum can further tighten the magnetic field upper limit to $B_0 \lesssim 0.05$ nG. These sub-nanoGauss constraints from the magnetic trispectrum are the most stringent limits so far on the strength of primordial magnetic fields, on megaparsec scales, significantly better than the limits obtained from the CMB bispectrum and the CMB power spectrum. This work has been done in collaboration with K. Subramanian and T.R. Seshadri.

Paniveni Udayashankar

Chaotic and turbulent supergranulation

While it is generally understood that supergranulation is a solar convective phenomenon, a detailed model can be quite complicated because of the interplay of magnetic and velocity fields and turbulence. The chaotic and turbulent aspect of the solar supergranulation can be studied by examining the inter-relationships amongst the parameters characterizing supergranular cells, namely, size, horizontal flow field, lifetime and physical dimensions of the cells and the fractal dimension deduced from the size data. The findings are supportive of Kolmogorovs theory of turbulence.

A. A. Usmani

A relativistic model for strange quark star

We have proposed a spherically symmetric and anisotropic model for strange quark stars within the framework of MIT Bag model. Though the model is found to comply with all the physical requirements of a realistic star satisfying a strange matter equation of state (EOS), the estimated values the Bag constant for different strange star candidates like Her X-1, SAX J 1808.4-3658 and 4U 1820-30, clearly indicate that the Bag constant need not necessarily lie within the range of 60 - 80 MeV fm^{-3} as claimed in the literature. This work has been done in collaboration with M. Kalam, F. Rahaman, Sk. M. Hossein, I Karar and R. Sharma.

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(b) Proceedings

1. **Prasad Basu,** and **Soumen Mondal (**2013) *A new model of relativistic equation of state in accretion and wind flows using 4-velocity distribution*, Conf. Proc. of Recent Trends in the study of Compact Objects: Theory and Observation, ASI Conf. Ser., **8**, 123.

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4. **Bhag Chand Chauhan,** *An imperative course of science*, Conf. Proc. of AISSQ-2014.

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(c) Books

1. **Suresh Chandra**, and Mohit K. Sharma (2013) *Research Methodology*, Narosa Publishing House, New Delhi (ISBN: 978-81-8487-246-0) and Alpha Science International Ltd., Oxford (UK) (ISBN: 978-1-84265-803-1).

2. **Surajit Chattopadhyay** (2013) *A Study on the Statefinder Description of the Interacting Ricci Dark Energy*, Published in Mathematics and Computing : Current Research and Developments : Eds. Sk. Md. Abu Nayeem, Jyotirmoy Mukhopadhyay, S.B. Rao , Narosa Publishing House, New Delhi. (ISBN: 978-81-8487-321-4).

3. **L. N. Katkar** (2014) *Mathematical Theory of General Relativity*, Narosa Publishing House, New Delhi, (ISBN : 978-81- 8487-254-5).

4. **L. N. Katkar** (2014) *Problems in Classical Mechanics*, Narosa Publishing House, New Delhi, (ISBN : 978-81- 8487-353-5).

AWARDS

1. **Suresh Chandra**, *Research Appreciation Award* by the Lovely Professional University, Phagwara (Punjab) in 2013.

2. **Sunandan Gangopadhyay**, *Visiting Academic Position*, in the National Institute for Theoretical Physics, Stellenbosch University, South Africa.

3. Hemwati Nandan, *DAAD Fellowship*, by German Academic Exchange Service, under its re-invitation programme and visited the Department of Physics, University of Konstanz (Germany), Carl von Ossietzky University, Oldenburg (Germany) in September and October 2013.

4. **Hemwati Nandan**, Nominated as *District Coordinator, Science Forum* (Haridwar District), Uttarakhand State Council for Science and Technology (UCOST), Dehradun.

5. **Das Himadri Sekhar**, *Indo-US Research Fellowship* (2013), for conducting advanced research in the area of Physical Sciences with Ludmilla Kolokolova at University of Maryland, USA for 3 months.

6. **Pranjal Trivedi**, *Fulbright-Nehru Fellowship*, doctoral research at Johns Hopkins University, USA, in the field of cosmology with Marc Kamionkowski.

7. **Paniveni Udayashankar**, *Indira Gandhi Sadbhavana Gold medal*, for the contribution in the field of Research and Education.

Supervision of M. Phil. Thesis

1. **Iqbal Naseer Bhat** (2013) Thesis titled "Gravitational Waves and Their Recent Status", University of Kashmir, Srinagar, by Showkat Ahmad Moonga.

2. **Iqbal Naseer Bhat** (2013) Thesis titled "Understanding High Energy Gamma Rays from AGN's" University of Kashmir, Srinagar, by Zahir Ahmad Shah.

Supervision of Ph.D. Thesis

1. **Asis Chattopadhyay** and **Tanuka Chattopadhyay** (2013) Thesis titled "*Globular Clusters and Galaxy Formation- A Multivariate Statistical Analysis*", by Saptarshi Mondal, University of Calcutta, Kolkata.

2. **Himadri Sekhar Das** (2013) Thesis titled "*Modeling of the Light Scattering Properties of Cometary Dust*", by Abinash Suklabaidya, Assam University, Silchar.

3. **V.C. Kuriakose (**2013) Thesis titled "Probing the Active Galactic Nuclei using Optical Spectroscopy" , by Vivek M. Cochin University of Science and Technology, Kochi.

4. **V.C. Kuriakose (**2013) Thesis titled "Studies on Quasinormal Modes and Late-time Tails in Black Hole Spacetimes" by Nijo Varghese, Cochin University of Science and Technology, Kochi.

5. **A. Pradhan** (2014) Thesis tilted "*Certain Aspects of the Expansion of Bianchi I and II Universe with Time Varying Cosmological Constant Λ and Gravitational Constant G"*, by Chanchal Chawla, Sant Longowal Institute of Engineering and Technology (Deemed University), Longowal, Sangrur, Punjab.

6. **Shantanu Rastogi,** (2013) Thesis tilted "Multiwave length Study of Active Galactic Nuclei", by Shruti Tripathi, D.D.U. Gorakhpur University.

7. **Anjan Ananda Sen** (2014) Thesis titled "*Dark Side of the Universe and its Observational Signatures"*, by Gaveshna Gupta, Jamia Millia Islamia, New Delhi.

IUCAA SPONSORED MEETINGS AND EVENTS AT VARIOUS UNIVERSITIES IN INDIA

INAAD RADIO ASTRONOMY MEETING - II

The IUCAA Node for Astronomy and Astrophysics Development (INAAD), at Newman College, Thodupuzha, Kerala, conducted the Radio Astronomy Meeting - II at St. Thomas College, Kozhencherri, during May 8- 10, 2013.

[For details see Khagol, Issue No.95, July 2013]

WORKSHOP ON ASTRONOMY AND ASTROPHYSICS

The University of Rajasthan, Jaipur, had organised a Workshop on Astronomy and Astrophysics, during September 2-4, 2013.

[For details see Khagol, Issue No.95, July 2013]

WORKSHOP ON ASTRONOMICAL TECHNIQUES AND SCIENCE WITH VIRTUAL OBSERVATORIES

Workshop on Astronomical Techniques and Science with Virtual Observatories was held at the University of Kashmir, Srinagar, during September 23-26, 2013.

[For details see Khagol, Issue No.96, October 2013]

WORKSHOP ON ASTRONOMY AND PHYSICS FOR SCIENCE COMMUNICATORS

Workshop on Astronomy and Physics for Science Communicators was held at J.E.S.College, Jalna, Maharashtra, during September 26-27, 2013.

[For details see Khagol, Issue No.96, October 2013]

AUTUMN SCHOOL ON COSMOLOGY

Autumn School on Cosmology was conducted at the Department of Physics, BITS-Pilani Campus, in association with IUCAA, during November 5-15, 2013.

[For details see Khagol, Issue No.97, January 2014]

WORKSHOP ON LIGHT SCATTERING TECHNIQUES AND APPLICATION TO ASTRONOMY AND OTHER AREAS

Workshop on Light Scattering Techniques and Application to Astronomy and Other Areas was held at the S. N. Bose National Centre for Basic Sciences, Kolkata during November 19-21, 2013 and was jointly funded by the S. N. Bose National Centre for Basic Sciences, Kolkata and IUCAA.

[For details see Khagol, Issue No.97, January 2014]

INDO-US JOINT CENTRES MEETING

A meeting of the two joint Indo-US Centres (a) Class ACT of IUCAA, Caltech and St.Thomas College (b) Variable Stars of University of Delhi, SUNY Oswego, University of Florida, Gainesville, Texas A&M University and IUCAA was held at St. Thomas College, Kozhencherri during January 22-24, 2014. A special meeting was held to introduce IUSSTF and various research funding facilities available to a general audience

[For details see Khagol, Issue No.98, April 2014]

IUCAA-IUSSTF WORKSHOP ON VARIABILITY OF ASTRONOMICAL SOURCES

A three day workshop on the Variability of Astronomical Sources was conducted at St. Thomas College, Kozhencherri, during January 22-24, 2014.

[For details see Khagol, Issue No.98, April 2014]

INTRODUCTORY WORKSHOP IN ASTRONOMY AND ASTROPHYSICS

The workshop was held at Manipur University during February10-12, 2014 under the aegis of IUCAA, with partial financial support from the UGC's Special Assistance Fund of the Department of Physics of the University.

[For details see Khagol, Issue No.98, April 2014]

DEPARTMENT OF PHYSICS
COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY, KOCHI

Coordinator: V. C. Kuriakose
Jt. 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 studies. Under-graduate and Post-graduate students from neighbouring colleges and institutes 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, Observational Astronomy, Bose-Einstein Condensation and Quantum Optics. Nine research students are now working in these areas

Workshop on Astronomy Research: Opportunities and Challenges (August 12-14, 2013).

This workshop was mainly intended for those pursuing research in Kerala in areas like Astronomy, Astrophysics and Cosmology. In this workshop there were 24 presentations by young researchers, and these presentations were sandwiched by talks of A. Kembhavi (IUCAA), P. Sreekumar (IIA), A. N. Ramaprakash (IUCAA), P. Ajith (ICTS, TIFR), K. Indulekhja (MG University, Kottayam), Anand Narayanan (IIST, Thiruvananthapuram) and Koshy George (Kapteyn Astronomical Institute, Groningen University). P. P. Divakaran and Ranjeev Misra (IUCAA) were also present during the entire period of the workshop to give guidelines and to help the young researchers. The various sessions were chaired by P. Sreekumar, A. Kembhavi, A. N. Ramaprakash, Ranjeev Misra, P. P. Divakaran, V. C. Kuriakose, K. Indulekha and C.D. Ravikumar. This workshop was held at MACFAST, Thiruvalla and Ninan Sajeeth Philip and Joe Jacob were the local organizers of this programme.

Publications

IRC facilities have been used for the following publications/presentations.

(a) In Refereed Journals

1. Dirac quasinormal modes of MSW black holes, Saneesh Sebastian and V. C. Kuriakose, Mod. Phys. Lett. A., 29, 1450019 (2014).
2. Scattering of Scalar field around an extended black hole in F(R) gravity, Saneesh Sebastian and V. C. Kuriakose, Mod. Phys. Lett. A., 29, 1450005 (2014).
3. Scalar filed evolution and area spectrum for Lovelock-AdS black hole, C. B. Prasobh and V. C. Kuriakose, Gen. Rel. Grav., 45, 2441(2013).

4. Spectroscopy and thermodynamics of MSW black hole, Saneesh Sebastian and V. C. Kuriakose, Mod. Phys. Lett. A., 33, 13501(2013).
5. Study of young stellar objects and associated filamentary structures in the inner Galaxy, B. Bhavya, Annapurni Subramaniam and V. C. Kuriakose, MNRAS, **435**, 663 (2013).
6. Thermodynamics and quasinormal modes of Park black hole in Hoˇrava gravity, Jishnu Suresh and V. C. Kuriakose, Eur. Phys. J. C, **73**, 2613 (2013).
7. Area spectrum and thermodynamics of KS black holes in Hoˇrava gravity, Jishnu Suresh and V. C. Kuriakose, Gen. Rel. Grav., **45**, 1877(2013).
9. Thermodynamics and spectroscopy of charged dilaton blackholes, R. Tharanath and V. C. Kuriakose, Gen. Rel. Grav., **45**, 1761 (2013).

(b) Oral presentations in Workshop on Astronomy Research: Opportunities and Challenges

1. Bhavya. B: Young stellar objects and associated filamentary structures in the inner galaxy.
2. Nijo Varghese: Decay of Dirac field around black hole in an expanding Universe.
3. R. Tharanath: Second order phase transition and quasinormal modes of Schwarzschild black hole in quintessence field.
4. Saneesh Sebastian: Scattering of scalar field around an extended Schwarzschild black hole
5. P. Prasia: Massive gravity in f(R) theory.
6. Jishnu Suresh: Area spectrum and thermodynamics of KS black holes in Horava gravity.

IRC Seminars

1. J. V. Narlikar (IUCAA): The quasi-steady state cosmology: A status report (Nov. 23, 2013).
2. Annapurni S. (IIA**):** Our Galaxy: How much do we know? (Jan. 10, 2014).

Lectures given by the Coordinator, IRC

1. St. Teresa's College, Ernakulam : Windows onto the Universe (Jan. 9 and 10, 2014).
2. MACFAST, Thiruvalla: Astronomy and high energy astrophysics- An introduction (Jan. 22, 2014).
3. Jai Bharath Training College, Thrikkakara : Basic ideas in Astronomy (Feb. 26, 2014).

The Coordinator has also taken part in discussions on Scientific topics of current importance in TV channels and All India Radio.

Public Outreach Programmes

1. Physics: Scope awareness programme for school students

Department of Physics, CUSAT, has organized a workshop for school students during April 1-6, 2013 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 to the astronomy programme, there were lectures on other topics in physics, and the students were given training on doing experiments 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.

2. Lectures, telescope making and sky watching programmes at school:

Because of the bad weather, this year we could visit only one college as part of the outreach programme, at U. C. College, Aluva, (Dec. 13, 2013). The programme consisted of lectures in general Astronomy, introduction of stellarium software, giving training in making small telescope and sky watching.

DEPARTMENT OF PHYSICS
COCHIN UNIVERSITY OF SCIENCE AND TECHNOLOGY, KOCHI

Coordinator: V. C. Kuriakose
Jt. Coordinator: Ramesh Babu T.

J. V. Narlikar giving a seminar at the Department of Physics, CUSAT

DEPARTMENT OF PHYSICS AND ASTROPHYSICS
UNIVERSITY OF DELHI

Coordinator: T. R. Seshadri
Jt. Coordinator : H.P. Singh

Seminars:

Cosmology from galaxy clusters: Acceleration of the universe and modified gravity by Neelam Dhanda, April 3, 2013.

New perspectives on Hawking radiation by Suprit Singh (IUCAA), May 1, 2013.

What can we learn from neutron star X-ray binaries? Harsha Raichur (Raman Research Institute, Bangalore), August 1, 2013.

On the generation of large-scale magnetic field due to fluctuations in turbulent helicity by Nishant Kumar Singh, (IUCAA), August 2, 2013.

Tomographic studies of pulsar radio emission cones by Yogesh Mann (Raman Research Institute, Bangalore) September 13, 2013.

On dynamics and structure of the gas in between the stars by Prasun Dutta (NCRA), September 25, 2013.

Spatial extent of star formation in interacting galaxies by Gunjan Bansal, September 25, 2013.

Impact of reionization scenarios on inflationary parameters by Arpan Das, October 23, 2013.

Origin of coherent magnetic fields on small and large scales by Pallavi Bhat (IUCAA), January 2, 2014.

In addition, the Centre is a hub of academic activity of people in astronomy and astrophysics as well as high energy physics. Regular discussion sessions in topics people are working in, Journal Club talks and brief discussions on recent papers are a regular feature. Two Ph.D. theses have been submitted, which have made extensive use of the facilities at IRC.

DEPARTMENT OF STATISTICS
CALCUTTA UNIVERSITY, KOLKATA

Coordinator: Asis Kumar Chattopadhyay
Jt. Coordinator: Narayan Banerjee

Research

During this period, the main focus of the research work was on Astrophysical data analysis. Research scholars and faculty members of different colleges and Universities in and around Kolkata were very much involved in the use of Mathematical and Statistical techniques as well as development of Computer programmes for the appropriate analysis of Astronomical data. They were 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 has been also going on.

The following project works have been carried out by the post graduate students of Calcutta University at this centre.

1. The evolution of stellar population in a giant galaxy by Arpita Ghosh, Department of Applied Mathematics, Calcutta University. Supervised by: Tanuka Chattopadhyay
2. H-R diagram of stars for a real data set of stellar parameters by Shreyasi Bose, Department of Applied Mathematics, Calcutta University. Supervised by: Tanuka Chattopadhyay
3. On lambda cosmological model of the universe by Jayita Marik, Department of Applied Mathematics, Calcutta University. Supervised by: Tanuka Chattopadhyay
4. H-R diagram of globular clusters by Pradip Mondal, Department of Applied Mathematics, Calcutta University. Supervised by: Tanuka Chattopadhyay
5. Estimation of masses of galaxy groups by different methods by Biswajit Choudhury, Department of Applied Mathematics, Calcutta University.Supervised by: Tanuka Chattopadhyay
6. Dimension reduction and clustering of galaxies by Bhaskar Saha and Soumyajita Sarkar, Department of Statistics, Calcutta University. Supervised by: Asis Chattopadhyay

Workshops and Meetings

(a) Workshop on Analysis of Astronomical Data, December 16-17, 2013 jointly organized by IRC North Bengal University and IRC Calcutta University

The coordinators of the workshop were B. C. Paul (NBU) and A. Chattopadhyay (CU). Thirty five M. Sc. students, research scholars and young college teachers from different institutes and universities attended the workshop. Several data analytic techniques as well as models related to Astrophysics and Cosmology were discussed by six eminent speakers.

Didier Fraix Burnet (IPAG, Grenoble,France) represented multivariate evolutionary analyses in astrophysics through Astrocladistics. Asis Chattopadhyay (Calcutta University) focused on different statistical techniques available under ASTROSTAT (formerly VOSTAT) for the analysis of astronomical data. Bikash Pal (North Bengal University) discussed some concepts of Cosmological model. Ayanendra Nath Basu (Indian Statistical Institute, Kolkata) illustrated the usefulness of robust statistical methods in Astrophysics. Tanuka Chattopadhyay (Calcutta University) described the motivation for clustering and classification of galaxy data. Sachindra Naik (Physical Research Laboratory, Ahmedabad) elaborated some problems related to high energy Astrophysics.

On both the days in the second half, Sharmad Navelkar (IUCAA) and Saptarshi Mandal (Calcutta University) gave hands on training on the use of VOPLOT and ASTROSTAT.

(b) IUCAA Science and Astronomy Camp, January 10-12, 2014 at Birbhum Institute of Engineering and Technology, Suri, Birbhum

This Science and Astronomy Camp was organized by IUCAA through IRC Kolkata. With a view to patronizing interest among senior school students (belonging to Classes XI and XII from Science stream) in Astronomy and Astrophysics. Also there were telescopic observations of the night sky for senior school students. Along with BIET, the event was also co-hosted by South Howrah Citizens' Forum.

The three-day programme was coordinated at BIET by Amitabha Ghosh, Distinguished Professor, BESU and former Director IIT, Kharagpur. The programme was conducted under the overall guidance of Bhabes

Bhattacharya, Director, BIET. More than 60 highly motivated students participated in the programme from different parts of West Bengal. All the resource persons ignited the imagination of the participants through their thought-provoking talks and presentation of slides .

The night sky observation facilities with the aid of telescopes with multiple orientations were supervised by Bipash Dasgupta, Ex-Scientific Advisor, Positional Astronomy Centre, Kolkata and he was well supported by Biplab De and Palash Baral from West Bengal sky watchers' association. The participants enjoyed with wonder, zeal, and appreciated the beauty and mystery of the stars in the clear sky.

On the evening January 11, 2014, a short Quiz Programme (objective type) was conducted by Amitabha Ghosh to shortlist 10 participants for the Summer Programmes at ARIES, Nainital.

(c) Seminar on Astronomy and Astrophysics, February 1, 2014 at Charuchandra College, Kolkata

This seminar was organized by the Department of Physics, Charuchandra College, Kolkata in collaboration with IRC Kolkata.

Among the speakers, Narayan Banerjee of IISER Kolkata delivered a talk on 'Our Universe' and Parthasarathi Majumdar of RKMV University, Belur discussed on 'Blackhole Mystries'. There was an arrangement for display and demonstration of solar equipments also. Keka Basuchaudhuri, coordinator of the programme, delivered the formal vote of thanks.

Publications

(a) Analysis of partial ordinal longitudinal data, Kalyan Das, Surupa Roy, and Asis Kumar Chattopadhyay, Brazilian J. Probability and Statistics, 2014 (Special Issue).
(b) Outlier detection through independent components for non-Gaussian data, Asis Kumar Chattopadhyay and Saptarshi Mondal, J. Indian Society of Agricultural Statistics, 2014 (Special Issue).
(c) Performance comparison of clustering techniques on the basis of galaxy data, Tuli De, Tanuka Chattopadhyay, and Asis Kumar Chattopadhyay, Calcutta Statistical Association Bulletin, 2013, 65 (257-258).
(d) Independent component analysis and clustering for pollution data, Asis Kumar Chattopadhyay, Saptarshi Mondal, and Atanu Biswas, Environmental and Ecological Statistics, 2013, *DOI 10.1007/s10651-014-0287-2* (online).
(e) Clustering large number of extragalactic spectra of galaxies and quasars through canopies Tuli De, Didier Fraix Burnet, and Asis Kumar Chattopadhyay, 2013 *hal.archives-ouvertes.fr/docs/ 00/ 86/ 18/73/.../SpectraCanopy (online).*

Seminars and Colloquia

What Physics and Astrophysics can detectors like LIGO-India teach us?, Speaker: Sukanta Bose, October 17, 2013.

Lectures by the Coordinator of IRC

(a) SAMSI, Research Triangle Park, North Carolina, USA, Analysis of Astronomical and Environmental Data (March 4-6, 2013).

(b) Indian Statistical Institute, Kolkata, Demographic Techniques (January 17, 2014).

(c) Visva Bharati, Shantiniketan, WB, Independent Component Analysis (February 22, 2014).

Visitor

Didier Fraix-Burnet, Astrophysique de Grenoble (*IPAG*) Université Joseph Fourie, Grenoble, France, December 10-20, 2013.

SCHOOL OF STUDIES IN PHYSICS AND ASTROPHYSICS
PT. RAVISHANKAR SHUKLA UNIVERSITY, RAIPUR

Coordinator: S. K. Pandey
Jt. Coordinator: R.C. Agarwal

Research Highlights

D. K. Chakraborty and his research group continued their work on intrinsic shape of elliptical galaxies and triaxial mass models. S. K. Pandey continued the collaborative research programme with A. K. Kembhavi, other colleagues and research students on multiwave length surface photometric studies of early-type galaxies.

Study of faint outermost regions of early-type galaxies from the Large Format Camera (LFC) field was carried out in collaboration with A. K. Kembhavi, Russell Cannon, and Ashish Mahabal. Investigation was done whether inner and outer parts of the early-type galaxies are different. Merger history of sample galaxies was speculated by comparing our results with the properties of isophotal shapes of merger remnants reported in the literature, obtained from N-body simulations. Laxmikant Chaware completed his thesis and was awarded PhD degree based on this work. A part of his thesis work has been accepted for publication in ApJ.

Samridhi Kulkarni has completed analysis of a sample of 40 dusty early-type galaxies as a part of her doctoral work during the year. An article entitled Study of dust and ionizied gas in early-type galaxies has appeared in New Astronomy (oneline). Thesis work was based on imaging observations of a sample of 40 early-type galaxies carried out using the observing facilities at IUCAA Giriwali Observatory (IGO) and Himalayan Chandra Telescopes, Hamle (IIA), and data analysis was carried out using the facilities available at IRC and Physics Department of the University. She would be submitting her thesis soon.

Sheetal Sahu (PhD student) carried out observations and analysis for his thesis work entitled “Multi-wavelength study of a sample of radio loud elliptical galaxies”. Surface photometry of sample galaxies were performed using the CCD data obtained with IGO 2m telescope, Pune. We have generated the colour maps, residual maps, and dust extinction maps, Hα emission maps of the galaxies helped to study the morphology of the dust and ionized gas content present in the galaxies. Detailed analysis of the dust properties were carried out for sample galaxies.

We have made use of the HST (WFPC2) archival optical images to investigate properties of the dust in the central region (~10 arcsec) of our sample galaxies. We have also estimated mass and temperature of the dust, molecular gas mass using FIR ? uxes of the galaxies obtained from IRAS. Spectroscopic archival data from SDSS (DR7) was used to get an estimate of the mass of the central super massive black-hole in NGC 4874. The rotation curve for coma cluster (Abell 1656) was made and we have found the presence of dark matter halo around the galaxy B2 1257+28 (NGC 4874).

Amit Tamrakar (PhD student) has started working on “Multiwave length isophotal shape analysis of early type galaxies”. As a part of this research programme it is proposed to carry out multi-band image analysis on a well defined sample of early type galaxies drawn from SDSS and other archives. These galaxies will be examined first for the presence of dust and other faint features embedded in them. Detailed isophotal shape analysis will be done on the sample galaxies to examine statistical correlations, if any, between presence of dust and other faint features with isophotal distortions quantified in terms of the higher order Fourier coefficients and other shape dependent parameters. This analysis is expected to improve our understanding as regards to the origin as well as the role of dust and other small scale features in the formation and evolution of early-type galaxies.

Mahendra Verma (PhD student) has initiated work on nuclear morphology of S0 galaxies. Sample galaxies are selected from the HST (Hubble Space Telescope) data archive. A variety of features, such as nuclear profiles, presence of nuclear cusps, inner stellar disks and dust distribution in the central regions, etc., in lenticular galaxies are proposed to be investigated and compare with similar studies on a well studied HST sample of ellipticals and spiral galaxies.

Research work on Supernovae (SNe) is being carried out by N. K. Chakradhari, and S. K. Pandey in collaboration with G. C. Anupama and D. K. Sahu, IIA, Bangalore. Photometric and spectroscopic optical observations were carried out using 2-m Himalayan Chandra Telescope. The UV data from Swift satellite were also analyzed. The work is mainly focused on Type Ia supernovae, which are believed to be thermonuclear explosions of carbon/oxygen white dwarf (WD), either accreting matter from the companion in a binary system or merging with another white dwarf. Their uniform peak luminosity makes them powerful distance indicators.

Interaction with the visiting scientists

Following scientists visited the IRC and interacted with the students: S. M. Chitre (TIFR, Mumbai), J. V. Narlikar, Mangla Jayant Narlikar, Arvind Gupta, Gulab Dewangan (All from IUCAA), T. P. Prabhu, Sunetra Giridhar, D. K. Sahu (All from IIA, Bangalore), Sudhanshu Barway (SAAO, South Africa), Asim Gangopadhyay (USA), and Niharika Thakur (USA).

Seminars and Popular lectures by visiting scientists

1. Indian facilities for observational Astronomy, T.P. Prabhu, IIA, Bangalore, Feb. 22, 2014.
2. Spectral classification: A tool to understand stars, Sunetra Giridhar, Feb. 06, 2014.
3. Virtual observatory: The cosmos on your desktop, Sudhanshu Barway, Jan. 25, 2014.
4. Measuring spin of supermassive black holes at the centres of active galaxies, Gulab Chand Dewangan, Jan. 06, 2014.
5. Outstanding problems in astrophysics, S.M. Chitre, Dec. 28, 2013.
6. Khel khel me vigyan, Arvind Gupta, Dec. 28 and Dec. 27, 2013.
7. Wonders in astrophysics, J. V. Narlikar, Dec. 26, 2013.
8. Fun with mathematics, Mangla J. Narlikar, Dec. 26, 2013.
9. Balloon borne experiment with a superconducting spectrometer in polar programme, Niharika Thakur, Research Scientist, NASA, USA, Nov. 23, 2013.

List of Publications

1. Isophotal shapes of early type galaxies to very faint isophotal levels, Laxmikant Chaware, Ajit Kembhavi, Russell D. Cannon, Ashish Mahabal, and S.K. Pandey, ApJ.
2. Study of dust and ionized gas in early-type galaxies, Samridhi Kulkarni, D. K Sahu, Laxmikant Chaware, N. K. Chakradhari, and S. K. Pandey, 2014, New A., **30**, 51.
3. One year of monitoring of the Type IIb supernova SN 2011dh, D. K Sahu, G. C. Anupama, and N. K. Chakradhari, 2013, MNRAS, **433**, 2.
4. Interpreting the large amplitude X-ray variation of GRS 1915+105 and IGR J17091-3624 as modulations of an accretion disc, Mayukh Pahari, Ranjeev Misra, Arunava Mukherjee, J. S Yadav, and S. K Pandey, 2013, MNRAS, **436**, 2334.
5. Properties of unique hard X-ray dips observed from GRS 1915+105 and IGR J17091-3624 and their implications, Mayukh Pahari, J. S. Yadav, Jérôme Rodriguez, Ranjeev Misra, Sudip Bhattacharyya, and S. K. Pandey , 2013, ApJ, **778**, 46.
6. A multiwavelength view of the ISM in the merger remnant galaxy Fornax A, Swati Pralhadrao Deshmukh, Bhagorao Tukaram Tate, Nilkanth Dattatray Vagshette, Sheo Kumar Pandey, and Madhav Khushalrao Patil, 2013, RAA, **13**, 885.
7. Multiband study of a lenticular galaxy, Sheetal Kumar Sahu, presented at 12th CG Young Scientist Congress, organized at Pt. Ravishankar Shukla University, Raipur in collaboration with CGCOST, during February 17-19, 2014.

Poster

Multiwave length study of radio loud early type galaxies from B2 Sample, Sheetal Kumar Sahu, L. K. Chaware, S. K. Pandey, M. B. Pandge, Samridhi Kulkarni, and N. K. Chakradhari, Presented at IAU symposium S304 : Multiwavelength AGN Surveys and Studies held at Yerevan, Armenia, October 7-11, 2013.

Activities and Public Outreach Programmes

1. National Science Day celebration was organized on March 8, 2013.
2. Planetarium Show, sky watching programme and telescope demonstrations were organized at various places for school/ college students, teachers and public.
3. Various activities were done during the INSPIRE summer and winter camps.

SCHOOL OF STUDIES IN PHYSICS AND ASTROPHYSICS
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Popular Lectures by S. K. Pandey:

1. Science Awareness Activities in Universities, at Jayant@75 organized at IUCAA, Pune, July 19, 2013.
2. Our Universe, at NIIT University, Neemrana (B. Tech. students), July 2013.
3. Reforms in Higher Education, at State Admin. Academy, Sept. 23, 2013.
4. Let us Know Our Universe, at the workshop "Eyes in ISON" Oct.5, 2013.
5. Life-Cycle of Stars, at The Science Centre, Raipur, Oct. 8, 2013.
6. A Journey into Our Universe, at Academic Staff College, Oct. 26, 2013.
7. Amazing World of Astronomy", at Govt Science College, Raipur, Jan. 20, 2014.
8. The Interface between Infinitesimal and Infinite: A Cosmic Connection, at the Rotary Club of Raipur, Feb. 14, 2014.
9. A Fresh View of the Universe: presents status and challenges ahead, Colloquium at Physics Department, IIT(BHU), Varanasi, Feb. 24,2014.
10. Where do we Come from?; Tracing the Cosmic Connection: Science Day Programme, SoS in Physics and Astrophysics, March 8, 2014.

N. K. Chakradhari delivered a lecture on Opportunities and Challenges in Physics and Astrophysics at Bhilai Mahila Mahavidyalaya, Bhilai, Jan. 16, 2014.

Ph. D. awarded

Laxmikant Chaware: Multiwavelength Study of Galaxies Using Deep Survey Fields (Feb. 2014).

DEPARTMENT OF PHYSICS, NORTH BENGAL UNIVERSITY, SILIGURI

Coordinator: B. C. Paul

Research Area

Cosmology, Compact Objects, Data Analysis of X-Ray Sources and Pulsars, Non-linear Dynamics

Workshop and Meetings

Workshop on Analysis of Astronomical Data **(December 16-17, 2013)**

IRC, NBU and IRC, Kolkata jointly organized this workshop. The coordinators of the workshop were B. C. Paul (NBU) and A. Chattopadhyay (CU). In the workshop thirty five M. Sc. students, research scholars and young college teachers from different institutes and universities attended. In the first half of the day, theories of DATA analysis techniques have been discussed by Didier Fraix Burnet (France), Asis Kr. Chattopadhyay (CU), and Ayanendra Nath Basu (ISI, Kolkata), Plenary lectures were given by Sachindra Naik (PRL, Ahmedabad), Bikash Ch. Paul (NBU), and Tanuka Chattopadhyay (CU). In the second half N. Sharmad (IUCAA, Pune) and S. Mandal (CU) gave hands on training on Virtual Observatory. T. Sarkar (NBU) presented a research paper.

Use of Data Centre: M. Sc. students have used the computers for their project work. Pragati Pradhan has done data analysis at IRC, NBU on X-ray pulsars.

List of Publications:

1. Relativistic charged star solutions in higher dimensions (2014) P. K. Chattopadhyay, R. Deb, and B. C. Paul, Int. J. Theor. Physics, **53**, 1666 DOI : 10.1007/s10773-013-1965-9.

2. Observational constraints on modified Chaplygin gas from cosmic growth (2013) B. C. Paul, and P. Thakur, JCAP, **11**, 052.

3. Revisiting SWJ2000.6+3210 : A persistent Be X-ray pulsar ? (2013) P. Pradhan, C. Maitra, B. Paul, and B. C. Paul, MNRAS, DOI; 10.1093/mnras/stt 1504.

4. Observational constraints on modified Chaplygin gas in Horava-Lifshitzg gravity with dark radiation (2013) B. C. Paul , P. Thakur, and M. M. Verma, Pramana J. Physics, **81**, 691.

5. Holographic dark energy with generalized Chaplygin gas in higher dimensions (2014) S. Ghose, A. Saha, and B. C. Paul , Int. J. Mod. Phys. D, **23** ,1450015.

6. Spectral lag features of GRB 060814 from Swift BAT and Suzaku Observations (2014) A. Roychoudhury, S. K. Sarkar, and A. Bhadra, ApJ., **782**, 105.

7. Astrophysical applications of Delbrück scattering: Dust scattered gamma radiation from gamma ray bursts (2014) B. Kunwar, A. Bhadra, and S. K. Sengupta, Rad. Phys. Chem., **95**, 326.

8. Novel late time asymptotics: Applications to anomalous transport in turbulent flow (2013) Dhurjati Prasad Datta, J. Radiation Effects and Defects in Solids, **168**, 789.

Seminars and Colloquia:

1. Astronomy and Astrophysics: Concepts and Challenges by D. P. Duari (M. P. Birla Institute of Fundamental Research, Kolkata) on 26.07.2013.
2. Dimensional Channel Material based MOSFETs: Grapheme FET and beyond by A. Sengupta (IISc, Bangalore) on 09.10.2013.
3. On Bose-Einstein Condensation by A. Tiwari (Sikkim University) on 10.03.2014.

Public Outreach Programmes

B. C. Paul has delivered the following popular talks:

1. Astronomy in India : Past and Present status at ASC, NBU on 20.03.2014
2. Why Higgs Boson or God Particle? at ASC, NBU on 27.02.2014

Visitors:

Soma Mandal	(Taki Govt. Colege)
P. Shalima	(IUCAA, Pune)
R. Deb	(Sikkim)
P. K. Chattopadhyaya	(Alipurduar)
P. Thakur	(Alipurduar)
Anirban Saha	(Barasat)
Saugata Mitra	(Jadavpur University)
Subhajit Saha	(Jadavpur University)
Ritabrata Biswas	(BESU, Shibpur)
S. Mondal	(Basanti Devi College, Kolkata)
T. Pal	(University of Calcutta)
Suvadip Roy	(CMI, Chennai)
P. Sanyal	(CMI, Chennai)
Ayanendra Nath Basu	(ISI, Kolkata)
Ranjan Sharma	(PD Women's College, Jalpaiguri)
A. Saha	(Jalpaiguri Govt. Engg. Colege, Jalpaiguri)
A. K. Chattopadhyay	(IRC, CU, Kolkata)
T. Chattopadhyay	(CU, Kolkata)
P. Pradhan, Souvik Gose	(SIEM, Siliguri)
Suchesmita Maiti	(A. B. N. Seal College, Coochbehar)
Romyani Goswami	(Surya Sen College, Siliguri)

DEPARTMENT OF PHYSICS,
MOHANLAL SUKHADIA UNIVERSITY, UDAIPUR

Coordinator: S. N. A. Jaaffrey

IUCAA Resource Centre (IRC), Udaipur was established in 2009 after signing a MOU between Mohanlal Sukhadia University, Udaipur and Inter-University Centre of Astronomy and Astrophysics, Pune. After reviewing the performance and progress of the IRC, MOU was renewed for next three year (2013-2016). The main motive of an IRC is to enhance the facilities to the teachers and students of colleges and universities of that region, involving the younger generation, who are pursuing research in Astronomy and Astrophysics, and in other related areas. The IRC would focus on research activities as well as to popularize Astronomy and Astrophysics among students and the general public.

To keep up the objectives at first priority, IRC, Udaipur has organized the following activities at various points of time :

The interior of the Data Centre of the IRC in which research scholars and M.Sc. students who opted the optional paper Astronomy and Astrophysics are at their computational work.

Outreach Activity on August 15, 2013

In order to start the IRC activities in the current session 2013-14 on the Independence Day of our nation, an outreach event on Introduction to Astronomy at St. Jonh's Nobel School was organized to popularize astronomical activities and awareness among school and college students of Rajasthan state in western India. This school is situated in the rural part of Udaipur city. Our outreach team comprising of Ravi Yadav, Surya Kant Joshi and Mahaveer Upadhyay, led by S. N. A. Jaaffrey (Coordinator of IRC) carried out various activities in different sessions for the school students of classes V to VIII. In the valedictory function, S. N. A. Jaaffrey, donated a Refractor Telescope to the school to involve students in astronomical activities and night sky watching programmes. Around 150 students with 15 teachers participated and asked various questions related to Universe, Stars, The Sun, Earth, Moon, etc. Among them one of the unique questions was “Why does the Sun change its colour and not twinkle like other stars do?”

Introductory lecture on astronomy by S.N.A.Jaaffrey.

Discussion with students.

Question and Answer session.

DEPARTMENT OF PHYSICS,
MOHANLAL SUKHADIA UNIVERSITY, UDAIPUR

Coordinator: S. N. A. Jaaffrey

Orientation Workshop on Comet ISON

Orientation Workshop on Comet ISON, which was sponsored by IUCAA, was conducted during November 22-23, 2013 at the Department of Physics, Mohanlal Sukhadia University, Udaipur. The comet ISON was discovered by the Russian astronomers Vitali Nevski and Artyom Novichonok, using the telescope network named International Scientific Optical Network (ISON). It could be seen with absolute brightness, utmost clarity, and could display a colourful cometary tail with dazzling display. The 'parabolic' orbit of the comet indicated that it probably originated from the outskirts of the solar system, perhaps from the Oort cloud. This comet was regarded as the greatest comet of the millennium. The magnitude of this comet was around –16; none of the comets in history had such a bright value, and far outshining the unforgettable Comet Hale- Bopp of 1997, and was very likely to outdo the long-awaited Comet Pan-STARRS (C/2011 L4). Northern hemisphere observers were highly favoured following its peak brightness in late November, and it remained visible without optical aid. The comet ISON plunged into the Sun, and ended its journey. Ranjeev Misra and S. N. A. Jaaffrey were the resource persons, and there were 7 lectures and screening of 2 documentary films, each on comet ISON and cosmic collisions in Universe. This was a very successful workshop, and the resource persons were the coordinators.

Part of the audience of the workshop

Question and Answer session

Night sky watching session with 6” telescope

DEPARTMENT OF PHYSICS,
MOHANLAL SUKHADIA UNIVERSITY, UDAIPUR

Coordinator: S. N. A. Jaaffrey

Outreach Activity

An outreach event on Introductory Astronomy at Gurunanak Public Senior Secondary School was organized on the National Science Day, February 28, 2014.

The outreach team comprising of Ravi Yadav, Surya Kant Joshi and Mahaveer Upadhyay led by S. N. A. Jaaffrey, has done various activities in different sessions for the school students of classes 11 and 12. There were about 250 students and 17 teachers participated in this outreach programme, which consisted of lectures, hands-on sessions, and screening of a documentary film on cosmic collision. At the end of the programme, there were question and answer sessions, and in the night, there was sky-watching programmes.

IRC team with students and teachers of Gurunanak Pubic Senior Secondary School, Udaipur

S. N. A. Jaaffrey with teachers and students

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 2014

Sr No.	FUNDS & LIABILITIES	Schedule No.	31.03.2014 Rs.
1	Trust Fund / Corpus	6	4,69,17,183
2	Grant-In-Aid from UGC	7	1,42,86,60,172
3	Other Project Grants	8	3,69,91,568
4	Projects and Other Payable (Net)	9	82,31,861
5	Current Liabilities	10 & 10A	83,82,568
6	Income and Expenditure a/c	14	(9,01,43,781)
	Total		1,43,90,39,571

Sr No.	ASSETS & PROPERTIES	Schedule No.	31.03.2014 Rs.
1	Fixed Assets (At cost)	11	1,08,66,43,825
2	Investments / Deposits	12	31,70,24,831
3	Project & Other Receivables (net)	13	47,81,783
4	Current Assets -	13	
	a) Cash, Bank balances & Revenue Stamps		69,02,039
	b) Loans and Advances	13A	1,31,34,998
	c) Deposits		23,32,016
	d) Prepaid Expenses		55,01,536
	e) Advance to Suppliers	13B	27,18,543
	Total		1,43,90,39,571

For Inter-University Centre for Astronomy & Astrophysics

M.S.Sahasrabudhe
Admin. Officer (Accounts)

N. V. Abhyankar
(Sr.Admn.Officer)

Prof. A.K.Kembhavi
(Director / Trustee)

Place : Pune
Date : 27.08.2014

As per Report of even date
For A.H.Joshi & Co.
Chartered Accountants
FRN- 110396W

S.A.Joshi
(Partner)
Membership No.037772

A. H. Joshi & Co. PUNE-30. Chartered Accountants

Chairperson
Governing Board

IUCAA

IUCAA, Post Bag 4, Ganeshkhind, Pune 411 007, India.
Phone : (020) 25691414; 25604100, Fax : (020) 25604699
Email : publ@iucaa.ernet.in, Web page : http://www.iucaa.ernet.in/