IUCAA

INTER-UNIVERSITY CENTRE FOR ASTRONOMY AND ASTROPHYSICS

(An Autonomous Institution of the University Grants Commission)

Annual Report

(April 1, 2009 – March 31, 2010)

Editor

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Highlights of 2009 - 2010

This annual report covers the activities of IUCAA during its twenty-second year, April 2009 - March 2010. The past year was particularly eventful for IUCAA. Ajit Kembhavi became the new director of IUCAA starting September 1, 2009. IUCAA held the first re-union meeting which brought together all the former faculty members, post-doctoral fellows, and students to share with the current IUCAA members their research interests, visions for growth and plans for expansion of the institute. The year 2009 being the International Year of Astronomy, IUCAA conducted about twelve special workshops across the country, in association with other institutions and Universities. The research activities and endeavours of IUCAA span different fronts, and are outlined in the pages of this report. Here, a quick summary and highlights are provided.

IUCAA has an academic strength of 17 core faculty members (academic), 14 post-doctoral fellows and 29 research scholars. The core research programmes by these academics span a variety of areas in astronomy and astrophysics. These topics include quantum theory and gravity, classical gravity, gravitational waves, cosmology and structure formation, cosmic microwave background radiation, observational cosmology and extragalactic astronomy, active galaxies, quasars and IGM, magnetic fields in astrophysics, high energy astrophysics, stars and the interstellar medium, and instrumentation. These research activities are summarised in pages 24 - 74. The publications of the IUCAA members, numbering to about 90 in the current year are listed in pages 109 - 113. IUCAA members also take part in pedagogical activities like lectures, seminars, popularisation of science, etc., the details of which are given in pages 118 - 120 and 123 - 130 of this Report.

The extended academic family of IUCAA consists of about 70 Visiting Associates, who have been active in several different fields of research. Pages 75 - 97 of this report highlights their research contributions. The resulting publications, numbering to about 80 are listed in pages 114 - 117 of this report. A total of about 1072 person-days were spent by Visiting Associates at IUCAA during this year. In addition, IUCAA was acting as host to about 650 visitors through the year. During the current year the Visiting Associates were drawn from 50 universities and colleges from all over India. The visitors to IUCAA came from over 150 institutions, universities and colleges which indicates the extent of participation of the university sector in IUCAA's activities.

IUCAA conducts its graduate school jointly with the National Centre for Radio Astrophysics, Pune. Among the research scholars, seven students have successfully defended their theses and obtained Ph.D. degree from the University of Pune during the year 2009 - 2010. Summary of their theses appears in pages 98 - 108.

Apart from these activities, IUCAA conducts several workshops, schools, and conferences each year, both at IUCAA and at different university/college campuses. *During this year, there were 10 such events in IUCAA and 5 were held at other universities/colleges under IUCAA sponsorship.*

Another main component of IUCAA's activities is its programme for Science Popularisation. On the National Science Day, several special events were organised, which included a special workshop on making simple spectroscopes. There were posters displayed by the academic members of IUCAA, which elaborated on the research work at IUCAA and topics in the field of astronomy. There were public lectures given by the faculty members and programmes for school students consisting of quiz, essay and drawing competitions. During the Open Day, about 4000 people visited IUCAA.

The activities carried out by IUCAA were ably supported by the scientific and technical, and administrative staff (27 and 31 in number respectively) who should get the lion's share of the credit for the successful running of the programmes of the centre. The scientific staff also looks after the major facilities like library, computer centre, IUCAA Girawali observatory and instrumentation lab. A brief update on these facilities is given on pages 162 - 167 of this Report.

Swara Ravindranath
Editor

Highlights of IUCAA activities in Indian Universities

From the time of its inception, one of IUCAA's main goals has been to encourage research and teaching of astronomy and astrophysics in Indian universities / colleges. **IUCAA Associateship Programme** is the main interface for faculty from Universities to visit and interact with the academic members of IUCAA. The associates are encouraged to stay typically for two weeks to about two months, with upto three visits per year. During the year 2009-2010, there were about 70 Associates from universities / colleges all over India, and 50 of them visited IUCAA for a total of 1072 days. Research students of the associates often accompany them during their visits, giving them an opportunity to discuss their research, and collaborate with IUCAA's faculty members. The continuing encouragement and support to universities by IUCAA is evident from about 80 publications in refereed journals by the associates during the past academic year, as well as their successful grant application and other academic achievements.

IUCAA conducts and also sponsors **workshops / schools on Astronomy** every year in the universities with an aim to encourage young students, spread awareness about the research opportunities, and also to train and encourage teachers to pursue research in astronomy. During 2009-2010, five workshops were held in universities on various topics, including optical observations and data analysis (Mohanlal Sukhadia University, Udaipur), galaxy photometry (Mahatma Gandhi University, Kottayam, Kerala), introductory astronomy and astrophysics (Panjab University, Chandigarh), advances in astronomy and astrophysics (University of Kashmir, Srinagar), recent trends in astronomy and astrophysics (Tezpur University, Assam). The workshops were held in various ***regional locations*** to ensure that all regions have access to them, and get exposed to emerging research topics.

Over the last few years, IUCAA has been encouraging collaborations from Universities to carry out **astronomical observations** using the 2-m telescope at IUCAA Girawali Observatory. The aim has been to involve members from the Universities in the research proposals, providing the ***initiative to lead the observing proposal***, justify the science, and to carry out the observations and data analysis. During the past year, 40% of the proposals included proposers from universities, with 32% being lead by a principal investigator from a university. About seven proposals were related to the thesis of Ph.D. students in Universities.

The **IUCAA Resource Centres** (IRCs) located at six different universities, across the country, have been actively participating in research activities in collaboration with academic members of IUCAA. In addition, they have also been independently holding workshops, organizing group discussions and other astronomy-related events. The IRCs have organized various workshops using local resource persons with expertise on various topics. IRC workshops on telescope making were conducted at North Bengal University, Siliguri; Pandit Ravishankar Shukla University, Raipur; Cochin University of Science and Technology, Kochi; and a workshop on physics of the stars was held at Delhi University. Cochin University of Science and Technology has introduced astronomy experiments to be carried out using the IGO telescope, as part of the M. Sc. programme. Major initiatives were taken by IUCAA during the year to procure all the necessary computers and data disks required to set up ***data centres at the IRCs***. The data centres are expected to be installed and become operational towards the end of 2010.

CONTENTS

The Council and the Governing Board

The Council *(As on March 31, 2010)*

President

Sukhadeo Thorat,
Chairperson,
University Grants Commission,
New Delhi.

Vice-President

Ved Prakash,
Vice-Chairperson,
University Grants Commission,
New Delhi.

Members

Anil Kakodkar,
(Chairperson, Governing Board),
DAE Homi Bhabha Chair Professor,
Bhabha Atomic Research Centre,
Mumbai.

G. Baskaran,
The Institute of Mathematical Sciences,
Chennai.

Samir K. Brahmachari,
Director General,
Council of Scientific and Industrial Research,
New Delhi.

Sanjay G. Dhande,
Director,
Indian Institute of Technology,
Kanpur.

N. S. Gajbhiye,
Vice-Chancellor,
Dr. Harisingh Gour University,
Sagar.

S. S. Hasan,
Director,
Indian Institute of Astrophysics,
Bengaluru.

K. Ramamurthy Naidu,
Banjara Hills,
Hyderabad.

A. M. Pathan,
Vice-Chancellor,
Maulana Azad National Urdu University,
Hyderabad.

A. N. Rai,
Vice-Chancellor,
Mizoram University, Aizwal.

S. Ramachandran,
Vice-Chancellor,
University of Madras, Chennai.

T. Ramasami,
Secretary,
Department of Science and Technology,
New Delhi.

M. Sami,
Centre for Theoretical Physics,
Jamia Millia Islamia,
New Delhi.

G. Sarojamma,
Vice-Chancellor,
Sri Padmavati Mahila Visvavidyalayam,
Tirupati.

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

Arun Adsool,
Acting Vice-Chancellor,
University of Pune,
Pune.

R. K. Chauhan
Secretary, University Grants Commission,
New Delhi.

Naresh K. Dadhich (Member Secretary),
Director,
IUCAA, Pune.

Sanjeev V. Dhurandhar,
IUCAA,
Pune.

Vijay Khole,
Vice-Chancellor,
University of Mumbai,
Mumbai.

G. Madhavan Nair
Chairperson,
Indian Space Research Organization
Bengaluru.

Rajaram Nityananda
Centre Director
National Centre for Radio Astrophysics
Pune.

Amitava Raychaudhuri
Director
Harish-Chandra Research Institute,
Allahabad.

R. C. Sobti
Vice-Chancellor
Panjab University, Chandigarh.

Ajay K. Sood
Indian Institute of Science, Bengaluru.

The following members have been inducted into the Council during the year

P. C. Agrawal,
Professor Satish Dhawan Professor of ISRO,
Tata Institute of Fundamental Research,
Mumbai.

Praveen Chhadah,
Director,
UGC-DAEF Consortium for Scientific Research,
Indore.

Mihir K. Chaudhuri,
Vice-Chancellor,
Tezpur University.
Tezpur.

Swarna Kanti Ghosh,
Centre Director,
National Centre for Radio Astrophysics,
Pune.

Niloufer Kazmi,
Secretary, University Grants Commission,
New Delhi.

K. Radhakrishnan,
Chairperson,
Indian Space Research Organization,
Bengaluru.

R. K. Shevgaonkar,
Vice-Chancellor,
University of Pune.
Pune.

Kandaswamy Subramanian,
IUCAA, Pune.

J. A. K. Tareen,
Vice-Chancellor,
Pondicherry University,
Pondicherry.

Member Secretary

Ajit K. Kembhavi,
Director, IUCAA, Pune.

The Governing Board

(As on March 31, 2010)

Chairperson

Anil Kakodkar

Members

S. S. Hasan
K. Ramamurthy Naidu

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

Arun Adsool
Sanjeev Dhurandhar
R. K. Chauhan
Vijay Khole
Rajaram Nityananda
Amitava Raychaudhuri
R. C. Sobti
Ajay Sood
Naresh Dadhich (Member Secretary)
Director, IUCAA

The following members have been inducted into the Governing Board during the year

P. C. Agrawal
Praveen Chhadah
Mihir K. Chaudhuri
Swarna Kanti Ghosh
Niloufer Kazmi
R. K. Shevgaonkar
Kandaswamy Subramanian
J. A. K. Tareen

Member Secretary
Ajit K. Kembhavi,
Director, IUCAA, Pune.

Honorary Fellows

Geoffrey Burbidge [Expired on January 26, 2010],
Centre for Astronomy and Space Sciences,
University of California, USA.

E. Margaret Burbidge,
Centre for Astronomy and Space Sciences,
University of California, USA.

Russell Cannon,
Anglo-Australian Observatory, Australia.

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

A. Hewish,
University of Cambridge, UK.

Gerard ‘t Hooft,
Spinoza Institute, The Netherlands.

Donald Lynden-Bell,
Institute of Astronomy,
University of Cambridge, UK.

Yash Pal,
Noida.

Allan Sandage,
The Observatories of the Carnegie Institution of Washington, USA.

P. C. Vaidya (Expired on March 12, 2010),
Gujarat University, Ahmedabad.

Visiting Professors

Roy Maartens,
Institute of Cosmology and Gravitation,
Portsmouth University, UK.

Alexei Starobinsky,
Landau Institute for Theoretical Physics,
Russia.

Statutory Committees

(As on March 31, 2010)

The Scientific Advisory Committee (SAC)

P. C. Agrawal,
Professor Satish Dhawan Professor of ISRO,
Tata Institute of Fundamental Research,
Mumbai.

Abhay Ashtekar,
Director, Institute for Gravitation and the Cosmos,
The Pennsylvania State University,
USA.

Deepak Dhar,
Tata Institute of Fundamental Research,
Mumbai.

Andrew C. Fabian,
Institute of Astronomy,
University of Cambridge, U. K.

Yashwant Gupta,
National Centre for Radio Astrophysics,
Pune.

Romesh K. Kaul,
The Institute of Mathematical Sciences,
Chennai.

P. N. Pandita,
North-Eastern Hill University, Shillong.

Martin M. Roth,
Astrophysikalisches Institut Potsdam (AIP),
Germany.

Naresh K. Dadhich (Convener till August 31, 2009),
Director, IUCAA, Pune.

Ajit K. Kembhavi (Convener from September 1, 2009)
Director, IUCAA,
Pune.

The Users' Committee

A. K. Kembhavi (Convener till August 31, 2009),
(Chairperson, Ex-Officio Member),
Director, IUCAA, Pune.

Arpana Arora,
Vice-Chancellor,
University College of Science,
Mohanlal Sukhadia University, Udaipur.

Dipankar Bhattacharya,
IUCAA, Pune.

Mihir K. Chaudhuri,
Vice-Chancellor,
Tezpur University, Tezpur.

Sanjeev Dhurandhar,
IUCAA, Pune.

Sarbari Guha,
Department of Physics,
St. Xavier's College, Kolkata.

M. K. Patil,
School of Physical Sciences,
Swami Ramanand Teerth Marathwada University,
Nanded.

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

The following members have served on the Committee for part of the year

Naresh Dadhich,
(Chairperson, Ex-Officio Member),
Director, IUCAA, Pune.

Tapodhir Bhattacharjee,
Vice-Chancellor,
Assam University, Silchar.

T. Padmanabhan,
IUCAA, Pune.

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

H. P. Singh,
Department of Physics and Astrophysics,
University of Delhi.

Parimal H. Trivedi,
Vice-Chancellor,
Gujarat University, Ahmedabad.

Anwar Jahan Zuberi,
Vice-Chancellor,
University of Calicut, Kozhikode.

The Academic Programmes Committee

Naresh K. Dadhich (Chairperson) (till August 31, 2009)
Ajit K. Kembhavi (Chairperson) (from September 1, 2009)
T. Padmanabhan (Convener)
Joydeep Bagchi
Dipankar Bhattacharya
Gulab C. Dewangan
Sanjeev V. Dhurandhar
Ranjan Gupta
Ranjeev Misra
Maulik Parikh
A. N. Ramaprakash
Swara Ravindranath
Varun Sahni
Tarun Souradeep
R. Srianand
Kandaswamy Subramanian
Shyam N. Tandon (till December 31, 2009)

The Standing Committee for Administration

Naresh K. Dadhich (Chairperson) (till August 31, 2009)
Ajit K. Kembhavi (Chairperson) (from September 1, 2009 and Member till August 31, 2009)
T. Padmanabhan
Sanjeev V. Dhurandhar (from September 1, 2009)
K. C. Nair (Member Secretary)

The Finance Committee

A. Kakodkar (Chairperson)
Ajit K. Kembhavi
N. A. Kazmi (from March 1, 2010)
Kandaswamy Subramanian
A. K. Dogra
S. K. Ghosh (from February 25, 2010)
T. R. Kem (from April 16, 2009)
K. C. Nair (Non-member Secretary)

R. K. Chauhan, Naresh K. Dadhich, Sanjeev V. Dhurandhar, Rajaram Nityananda, and A. Pimpale have served on the committee for part of the year.

Members of IUCAA

Academic

Ajit K. Kembhavi (Director)
T. Padmanabhan (Dean, Core Academic Programmes)
Sanjeev V. Dhurandhar (Dean, Visitor Academic Programmes)
Joydeep Bagchi
Dipankar Bhattacharya
Gulab C. Dewangan
Ranjan Gupta
Ranjeev Misra
Maulik Parikh
A. N. Ramaprakash
Swara Ravindranath
Varun Sahni
Tarun Souradeep
R. Srianand
Kandaswamy Subramanian
Naresh K. Dadhich (till August 31, 2009)
Shyam N. Tandon (till December 31, 2009)

Emeritus Professors

Jayant V. Narlikar
Naresh K. Dadhich (from September 1, 2009)
Shyam N. Tandon (from January 1, 2010)

Scientific and Technical

Prafull S. Barathe
Nirupama U. Bawdekar
Rani S. Bhandare
Santosh S. Bhujbal
Mahesh P. Burse
Shanker B. Chavan
V. Chellathurai
Kalpesh S. Chillal
Pravinkumar A. Chordia
Hillol K. Das
Samir A. Dhurde
Gajanan B. Gaikwad
Sudhakar U. Ingale
Abhay A. Kohok
Vilas B. Mestry
Shashikant G. Mirkute
Deepa Modi (from September 7, 2009)
Vijay Mohan
N. Nageswaran
Arvind Paranjpye
Sarah Ponrathnam
Swapnil M. Prabhudesai
Sujit P. Punnadi (from July 6, 2009)
Vijay Kumar Rai
Chaitanya V. Rajarshi
Hemant Kumar Sahu
Yogesh R. Thakare

Administrative and Support

K. C. Nair (Senior Administrative Officer)
Niranjan V. Abhyankar
Vijay P. Barve
Savita K. Dalvi
Sandeep L. Gaikwad
Bhagiram R. Gorkha
Bhimpuri S. Goswami
Ramesh S. Jadhav
Baban B. Jagade
Sandip M. Jogalekar
Swati D. Kakade
Santosh N. Khadilkar
Susan B. Kuriakose
Neelima S. Magdum
Manjiri A. Mahabal
Eknath M. Modak
Kumar B. Munuswamy
Rajesh D. Pardeshi
Rajesh V. Parmar
B. Ratna Rao (Retired on February 28, 2010)
Mukund S. Sahasrabudhe
Vyankatesh A. Samak
Senith S. Samuel
Balaji V. Sawant
Snehalata Shankar
Deepak R. Shinde
Varsha R. Surve
Deepika M. Susainathan
Sadanand R. Tarphe
Shankar K. Waghela
Kalidas P. Wavhal

Post-Doctoral Fellows

Kinjal Banerjee
Bhaswati Bhattacharyya (from October 9, 2009)
Radouane Gannouji
Harsha Raichur
Surajit Paul (from August 25, 2009)
Sanil Unnikrishnan (from July 1, 2009)
Manjari Bagchi (from September 15, 2009)
(till March 30, 2010)
Chiranjib Konar (till July 24, 2009)
Gauri Kulkarni (till October 31, 2009)
Siddharth Malu (till December 31, 2009)
Kuntal Misra (till September 25, 2009)
Pasquier Noterdaeme (till January 5, 2010)
Biswajit Pandey (till July 21, 2009)

Project Scientist

Rizwan Ansari (from March 2, 2010)

Research Scholars

Moumita Aich
Maryam Arabsalmani
Bruce Cabral (from July 23, 2009)
Susmita Chakravorty
Luke Chamandy (from July 31, 2009)
Saugata Chatterjee
Santanu Das (from January 4, 2010)
Tuhin Ghosh
Gaurav Goswami
Mohammad Hasan (from July 20, 2009)
Charles Jose
Nisha Katyal
Sanved Kolekar
Dawood Kothawala
Sandeep Kumar
Sibasish Laha
Dipanjan Mukherjee
Sowgat Muzahid
Hadi Rahmani
Aditya Rotti
Prashant Kumar Samantray
Suprit Singh (from August 3, 2009)
Mudit Kumar Srivastava
Kaustubh Vaghmare (from July 31, 2009)
Tanushree Basu (till June 26, 2009)
Gaurang Mahajan (till October 15, 2009)
Saumyadip Samui (till October 16, 2009)
Sudipta Sarkar (till July 3, 2009)
Sharanya Sur (till October 7, 2009)

Temporary/Project/Contractual Appointments

Tushar Agrawal
Neelam S. Bhujbal
Jeetendra S. Joshi (Observatory Support)
Santosh Jagade (from February 11, 2010)
Manisha S. Kharade (ERNET Project)
Manish Karjule (VLSI Project, from November 30, 2009)
Sharmad D. Navelkar (VO Project)
Nilesh Pokharkar (Observatory Support)
Ashok Rupner (MVS)
Sagar Shah
Sakya Sinha
Rucha Sule (Analogue Design, from November 30, 2009)
A. K. Tamrakar (Observatory Support, from
December 28, 2009)
Kirti Tonpe
Shrirang P. Zodage
Deoyani Nandrekar (till August 19, 2009)

Part-time Consultant

Vidula Mhaiskar (MVS)
Vitthal S. Savaskar (Medical Services)

Long Term Visitors

Arvind Gupta (MVS)
P. P. Divakaran
R. Tikekar
Ninan Sajeeth Philip (from January 2010)

Visiting Associates of IUCAA

G. Ambika,
Department of Physics,
Indian Institute of Science
Education and Research, Pune.

B. R. S. Babu,
Department of Physics,
University of Calicut, Kozhikode.

N. Banerjee,
Department of Physical Sciences,
IISER-Kolkata,
Mohanpur Campus, West Bengal.

S. K. Banerjee,
Department of Mathematics,
Univrsity of Petroleum and Energy Studies,
Dehradun

Vasudha Bhatnagar,
Department of Computer Science,
University of Delhi, Delhi

Gour Bhattacharya,
Department of Physics,
Presidency College, Kolkata.

Somenath Chakrabarty,
Department of Physics,
Visva Bharati, Santiniketan.

Pavan Chakraborty,
Robotics and AI Division,
Indian Institute of Information Technology, Allahabad.

Subenoy Chakraborty,
Department of Mathematics,
Jadavpur University, Kolkata.

Suresh Chandra,
School of Physics,
Shri Mata Vaishno Devi University,
Kakryal-Katra, Jammu and Kashmir.

Asis Kumar Chattopadhyay,
Department of Statistics,
Calcutta University, Kolkata.

Tanuka Chattopadhyay,
Department of Applied Mathematics,
Calcutta University, Kolkata.

Ajay S. Chaudhari,
School of Physical Sciences,
Swami Ramanand Teerth Marathwada University,
Nanded.

Rabin Kumar Chhetri,
Department of Physics,
Sikkim Government College, Gangtok.

H. S. Das,
Department of Physics,
Assam University, Silchar.

Ujjal Debnath,
Department of Mathematics,
Bengal Engineering and Science University, Howrah.

Jishnu Dey,
Department of Physics,
Presidency College, Kolkata.

Mira Dey,
Department of Physics,
Presidency College, Kolkata.

Ranabir Dutt,
Department of Physics,
Visva Bharati University, Santiniketan.

Sushant Ghosh,
Centre for Theoretical Physics,
Jamia Millia Islamia, New Delhi.

P. S. Goraya,
Department of Physics,
Punjabi University, Patiala.

Sarbari Guha,
Department of Physics,
St. Xavier's College, Kolkata.

K. P. Harikrishnan,
Department of Physics,
The Cochin College, Kochi.

N. Ibohal,
Department of Mathematics,
University of Manipur, Imphal.

Naseer Iqbal Bhat,
P. G. Department of Physics,
University of Kashmir, Srinagar.

S. N. A. Jaaffrey,
Department of Physics,
University College of Science,
M. L. Sukhadia University, Udaipur.

Joe Jacob,
Department of Physics,
The Newman College, Thodupuzha.

Deepak Jain,
Department of Physics and Electronics,
Deen Dayal Upadhyaya College, Delhi.

Sanjay Jhingan,
Centre for Theoretical Physics,
Jamia Millia Islamia, New Delhi.

Chanda Jog,
Department of Physics,
Indian Institute of Science, Bengaluru.

Kanti Jotania,
Department of Physics,
The M. S. University of Baroda, Vadodra.

Pushpa Khare,
Department of Physics,
Utkal University, Bhubaneswar.

Nagendra Kumar,
Department of Mathematics,
M. M. H. College, Ghaziabad.

V. C. Kuriakose,
Department of Physics,
Cochin University of Science and Technology, Kochi.

Manzoor A. Malik,
Department of Physics,
University of Kashmir, Srinagar.

Pradip Mukherjee,
Department of Physics,
Presidency College, Kolkata.

K. K. Nandi,
Department of Mathematics,
North Bengal University, Siliguri.

Sanjay Pandey,
Department of Mathematics,
L. B. S. (P. G.) College, Gonda.

S. K. Pandey,
School of Studies in Physics,
Pt. Ravishankar Shukla University, Raipur.

P. N. Pandita,
Department of Physics,
North Eastern Hill University, Shillong.

K. D. Patil,
Department of Mathematics,
B. D. College of Engineering, Sevagram.

M. K. Patil,
School of Physical Sciences,
Swami Ramanand Teerth Marathwada University, Nanded.

B. C. Paul,
Department of Physics,
North Bengal University, Siliguri.

Ninan Sajeeth Philip,
Department of Physics,
St. Thomas College, Kozhencherri.

S. 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, Santiniketan.

Anirban Saha,
Department of Physics,
West Bengal State University, Barasat.

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

E. Saikia,
Department of Physics,
Inderprastha Engineering College, Ghaziabad.

Sanjay Baburao Sarwe,
Department of Mathematics,
St. Francis De Sales College, Nagpur.

Anjan Ananda Sen,
Centre for Theoretical Physics,
Jamia Millia Islamia, New Delhi.

Asoke Kumar Sen,
Department of Physics,
Assam University, Silchar.

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

K. Shanthi,
Academic Staff College, University of Mumbai.

H. P. Singh,
Department of Physics and Astrophysics,
University of Delhi.

M. Sivakumar,
School of Physics,
University of Hyderabad.

Pradeep K. Srivastava,
Department of Physics,
D. A. V. (P. G.) College, Kanpur.

Paniveni Udayashankar,
Department of Physics,
NIE Institute of Technology, Mysore.

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

Till July 31, 2009

Ashish Asgekar,
Department of Physics,
BITS-Pilani, Goa Campus.

Sukanta Dutta,
Department of Physics and Electronics,
S. G. T. B. Khalsa College, Delhi.

D. V. Gadre,
ECE Division,
Netaji Subhas Institute of Technology, New Delhi.

Moncy John,
Department of Physics,
St. Thomas College, Kozhencherri.

Avinash Khare,
Department of Physics and Astrophysics,
University of Delhi.

Sanjay Kumar Sahay,
Department of Physics,
BITS-Pilani, Goa Campus.

M. Sami,
Centre for Theoretical Physics,
Jamia Millia Islamia, New Delhi.

G. P. Singh,
Department of Mathematics,
Visvesvaraya National Institute of Tech., Nagpur.

From August 1, 2009

Sk. Saiyad Ali,
Department of Physics,
Jadavpur University, Kolkata.

S. N. Borah,
Department of Physics,
DKD College, Dergaon, Assam.

Anjan Dutta,
Department of Physics and Astrophysics
University of Delhi, Delhi.

Minu Joy,
Department of Physics
Alphonsa College, Pala, Kerala.

Mamta,
Department of Physics and Electronics,
SGTB, Khalsa College, Delhi.

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

Ranjan Sharma,
Department of Physics
P. D. Women's College, Jalpaiguri

Pranjal Trivedi,
Department of Physics,
Sri Venkateswara College, Delhi.

The twentieth batch of Visiting Associates, who were selected for a tenure of three years, beginning August 1, 2009

Sk. Saiyad Ali

S. N. Borah

Anjan Dutta

Minu Joy

Mamta

Farooq Rahaman

Ranjan Sharma

Pranjal Trivedi

Appointments of the following Visiting Associates from the seventeenth batch were extended for three years : B. R. S. Babu, Shyamal Kumar Banerjee, Sarbari Guha, Ngangbam Ibohal, Joe Jacob, Deepak Jain, Bikash Chandra Paul, C. D. Ravikumar, Sandeep Sahijpal, Asoke Kumar Sen, K. Shanthi, and M. Sivakumar.

Organizational Structure of IUCAA's Academic Programmes
(From September 1, 2009)

The Director
Ajit K. Kembhavi

Dean, Core Academic Programmes
(T. Padmanabhan)

Head, Computing Facilities
(Dipankar Bhattacharya)

Head, IUCAA Girawali Observatory
(Vijay Mohan)

Head, Publications
(T. Padmanabhan)

Head, Instrumentation
(A. N. Ramaprakash)

Head, Library
(Varun Sahni)

Head, Teaching Programmes
(K. Subramanian)

Dean, Visitor Academic Programmes
(S. V. Dhurandhar)

Head, Public Outreach Programmes
(Gulab C. Dewangan)

Head, Scientific Meetings
(Ranjan Gupta)

Head, Estate Development and Maintenance
(Ajit K. Kembhavi)

Head, Visitor Programmes and IUCAA Resource Centres
(Ranjeev Misra)

Head, Infrastructural Facilities
(Tarun Souradeep)

Head, Observing Programmes and SALT
(R. Srianand)

Director's Report

On August 31, 2009 I took over as the Director of IUCAA from Professor Naresh Dadhich on his superannuation. Professor Dadhich is one of the founder members of IUCAA and has the distinction of being the first employee of the institute, which he served in various capacities. He has contributed immensely to the development of the institute and initiated many new scientific programmes. Professor Dadhich was closely identified with developing programmes for the universities, and in addition to all his scientific activities also contributed to various expressions of art in IUCAA. Another person to retire after a long career as an astronomer, first at TIFR in Mumbai and then at IUCAA, was Professor Shyam Tandon. He contributed immensely to the development of the instrumentation programme at IUCAA and the setting up of the 2 metre telescope near Girawali. Naresh Dadhich and Shyam Tandon are now Emeritus Professors at IUCAA. Professor Tandon continues to make important contributions to the development of the Ultra Violet Imaging Telescope (UVIT) for the ASTROSAT.

The academic and technical staff at IUCAA have continued to make significant contribution to research and development in theory, observation and instrumentation. The IUCAA 2 metre telescope is now routinely being used by astronomers from IUCAA, the universities and various research institutions in India for observations. A number of observing projects, some of which push the telescope to its limits, have been undertaken, and publications based on observations with the telescope have appeared in international journals. The 10 metre Southern African Large Telescope (SALT), in which IUCAA is a partner, is expected to become operational by the end of October 2010, with some technical difficulties, which had affected the image quality being satisfactorily resolved. SALT will be used by astronomers at IUCAA and in the universities for state-of-the-art observations.

The instrumentation group at IUCAA has entered into a collaboration with the University of Wisconsin, USA, which is also a partner in SALT, for developments related to the infrared arm of the Robert Stobie spectrograph on SALT. The instrumentation group is also collaborating with astronomers at Caltech for the development of an affordable adaptive optics system, which could be used on 2 metre class telescopes.

The computer centre has made significant progress by setting up a state-of-the-art Data Centre and High Performance Computing facilities, and the Virtual Observatory programme has successfully developed and delivered Proposal Management System and Data Archival Systems for the Giant Metrewave Radio Telescope (GMRT) and IUCAA Girawali Observatory (IGO). The development of a Radio Physics Laboratory for university and college students, in collaboration with the National Centre for Radio Astrophysics (NCRA) has been completed.

IUCAA as an Inter-University Centre has continued to initiate new programmes for universities and colleges. An important step in this direction has been the setting up of Astronomical Data Centres at each of the six IUCAA Resource Centres (IRCs), which are now located at North Bengal University, Darjeeling; Delhi University; Pt. Ravishankar Shukla University, Raipur; Calcutta University; Cochin University of Science and Technology, Kochi and M. L. Sukhadia University, Udaipur. These data centres will help teachers and students in these universities and regions around to develop experience in data management and analysis. A series of workshops have been carried out at IUCAA as well as in various university campuses to provide hands-on training to research students in the use of astronomical data, with particular emphasis on X-ray data. These training sessions have enabled the students and their guides to formulate doctoral research projects. IUCAA faculty members have been lecturing at the post-graduate and research levels, in some universities and colleges as a part of the formal course work of the students, who have also visited IUCAA to carry out practical work. It is expected that there will be significant increase in such teaching and workshop activity at IUCAA after planned expansion of some of its facilities, including the hostel and guest house, are completed in the coming year.

As is usual, a number of workshops and other meetings were conducted on the IUCAA campus, in the IRCs and at other university campuses. A memorable meeting was the reunion organized to celebrate the first twenty years of IUCAA. IUCAA alumni from all over the world, as well as many of the people who have served on various IUCAA committees and helped to set up the institution, came to the meeting to make it an exciting scientific, social and cultural experience. It was satisfying to see how far and wide IUCAA alumni have spread, and how much they were contributing to many great institutions. Another important meeting was a conference on High Performance Computing (HPC) in Astronomy organized at IUCAA in October 2009 in collaboration with the National Centre for Radio Astrophysics and the Centre for Development of Advanced Computing. Some of the leading people in the world working on the application of HPC to various aspects of astronomy came to the meeting. Another interesting event was the VIth International Conference on Library Information Services in Astronomy organized at IUCAA in February 2010, with discussions on astronomy librarianship in the 21st century as the main theme.

IUCAA has contributed significantly to activities related to the International Year of Astronomy (IYA), which was celebrated during the calendar year 2009 to commemorate the first astronomical observations made by Galileo Galilei, 400 years ago. A number of lectures on various current topics in astronomy were delivered by IUCAA members all over the country, and 13 telescope making and simple spectroscopy workshops for school students were conducted by IUCAA through its public outreach programme.

A number of IUCAA students, as well as research students from the universities, who have been carrying out some of their work under the supervision of IUCAA faculty members, have completed their Ph.D.s during the current academic year, and have obtained excellent post-doctoral fellowships in leading astronomical research centres in the world.

Looking to the future, IUCAA together with the Indian Institute of Astrophysics, Bangalore and ARIES, Nainital has submitted a Detailed Project Report seeking the Government of India's approval for becoming a partner in the very exciting and futuristic Thirty Metre Telescope (TMT) project. This project is being executed through an international collaboration and the TMT, which will be located in Hawaii, is expected to become operational by 2018. If the project is approved, the TMT will provide opportunities for state-of-the-art observations in the optical and near-infrared domains by Indian astronomers in various institutes and universities.

There is growing need for additional space in IUCAA to accommodate new computer resources and instrumentation laboratories. There is also a requirement of additional guest house facilities for the increasing number of visitors coming to IUCAA. New construction activity has, therefore, been undertaken and it is expected that additional space will become available in the second half of 2011.

I wish to thank the Governing Board and Governing Council of IUCAA, and in particular their respective Chairpersons, Dr. Anil Kakodkar and Professor Sukhadeo Thorat, for the guidance and support that they provide to IUCAA and to me personally. Our work would not have been possible without the great support provided by the University Grants Commission and its officers, and most importantly, the scientific, technical and administrative staff of IUCAA.

Ajit Kembhavi
(Director)

Congratulations to...

Gulab Dewangan for receiving the **COSPAR Associateship**, for guiding students on a project on Fermi gamma-ray study of Blazars at the 11th COSPAR capacity building workshop at the Raman Research Institute, Bangalore, India, during February 8 - 19, 2010.

J. V. Narlikar on receiving the ***Swatantryaveer Savarkar Vidnyan Puraskar 2009*** awarded by Swatantryaveer Savarkar Rashtriya Smarak, Mumbai.

J. V. Narlikar, on being conferred with the ***Maharashtrabhushan Award*** by Maharashtra Times, Mumbai.

J. V. Narlikar on receiving the ***Purushottam Puraskar*** from Shri P. K. Anna Patil Foundation, Shahada.

J. V. Narlikar on receiving the ***S. L. Gadre Puraskar*** from the Maharashtra Seva Sangh, Mumbai.

T. Padmanabhan on being elected ***President*** of Commission-47 of the International Astronomical Union.

T. Padmanabhan, on being awarded with the ***Infosys Prize 2009*** for Physical Sciences by Infosys Science Foundation, Bengaluru.

P. N. Pandita, Visiting Associate and Scientific Advisory Committee member of IUCAA, on being awarded the ***J. C. Bose National Fellowship*** by the Department of Science and Technology, Government of India, New Delhi.

Ashok Rupner, on being conferred with the ***Award for Most Innovative Workshops*** by Scifest Africa, 2010.

Mudit Srivastava, for being awarded the ***COSPAR Fellowship*** for the year 2009 to work on a project entitled "Characterization of Micro-Channel Plate (MCP) based Photon Counting Detectors for UV Spectroscopy on World Space Observatory - UV mission", at Institute for Astronomy and Astrophysics (IAAT), University of Tuebingen, Germany.

K. Subramanian, on being elected ***Fellow of Indian Academy of Sciences,*** **Bangalore.**

Shyam N. Tandon on being the recipient of the UGC National Hari Om Ashram Trust Award, entitled ***Sir C. V. Raman award*** for Research in Physical Sciences.

Welcome and Farewell

Welcome to...

Bhaswati Bhattacharyya, who has joined as a Post-doctoral Fellow. Her areas of research are Pulsars : Search, Single Pulse Study, and Polarization.

Manjari Bagchi, who has joined as a Post-doctoral Fellow. Her areas of research are Pulsars in Globular Clusters, Radio Pulsar Timing Analysis, and Observable Properties of Neutron and Strange Stars.

Surajit Paul, who has joined as a Post-doctoral Fellow. His areas of research are Cosmological Structure Formation Shocks, Computational Astrophysics, Modelling Shocks and Turbulences, and Radio Observations of Large Scale Structures.

Sanil Unnikrishnan, who has joined as a Post-doctoral Fellow. His areas of research are Cosmological Perturbations Theory, Dark Energy, Cosmic Microwave Background Radiation, and Modified Gravity Models.

Luke Chamandy, **Santanu Das, Mohammad Hasan**, **Suprit Singh**, and **Kaustubh Vaghmare**, who have joined as Research Scholars.

Rizwan Ul Haq Ansari, who has joined as a Project Scientist. His areas of research are Cosmological Perturbation Theory, Dark Energy, and Braneworld Cosmology.

... Farewell to

Manjari Bagchi, who has joined the West Virginia University, Morgantown, USA, as a Post-doctoral Fellow.

Tanushree Basu, who has joined the Physical Research Laboratory, Ahmedabad, as a Junior Research Fellow.

Susmita Chakravorty, who has joined the Harvard University, Cambridge, USA, as a Post-doctoral Fellow.

Chiranjib Konar, who has completed his tenure as a Post-doctoral Fellow at IUCAA, and joined the Indian Institute of Astrophysics, Bangalore, as a Post-doctoral Fellow.

Gauri V. Kulkarni, who has completed her tenure as a project Post-doctoral Fellow.

Gaurang Y. Mahajan, who has submitted his Ph.D. thesis to the University of Pune.

Siddharth S. Malu, who has joined the Raman Research Institute, Bengaluru, as a Post-doctoral Fellow.

Kuntal Misra, who has joined the Space Telescope Science Institute, Baltimore, U. S. A., as a Post-doctoral Fellow.

Pasquier Noterdaeme, who has joined the European Southern Observatory, Santiago, Chile, as a Scientific Visitor.

Biswajit Pandey, who has joined the Visva Bharati University, Santiniketan, as a Lecturer in Physics.

Sudipta Sarkar, who has joined the University of Maryland, U. S. A., as a Post-doctoral Fellow.

Saumyadip Samui, who has joined the SISSA, Italy, as a Post-doctoral Fellow, to work on the Herschel project.

Sharanya Sur, who has joined the Institute for Theoretical Astrophysics, University of Heidelberg, Germany, as a Post-doctoral Fellow.

Calendar of Events

2009

April 13 – May 22
School Students' Summer Programme at IUCAA

May 8
IUCAA-NCRA Graduate School Second semester ends

May 11 – June 12
Refresher Course in Astronomy and Astrophysics (for College/University teachers) at IUCAA

May 11 – June 26
Vacation Students' Programme at IUCAA

June 9 – June 10
Optical Observations and Data Analysis
at Mohanlal Sukhadia University, Udaipur

June 29 – July 3
Introductory Workshop for ASTROSAT Data Products Software Team at IUCAA

June13 – July 15
GSMT-India-GMT Meeting at IUCAA

August 3
IUCAA-NCRA Graduate School First semester begins

August 10
Satellite Meeting 1 : Indian Gravitational Wave Experimental Efforts – Scope and Feasibility at IUCAA

August 10
Satellite Meeting 2 : Large Data Sets and Follow up Observations at IUCAA

August 11 – 14
First IUCAA Reunion Meeting : Gravitation and Astronomy – Frontiers in Theory and Observations at IUCAA

October 12 – 16
International Workshop on High Performance Computing in Observational Astronomy : Requirements and Challenges (Jointly by IUCAA, NCRA, and C-DAC) at IUCAA

October 30 – November 5
Workshop on Galaxy Photometry
at Mahatma Gandhi University, Kottayam

October 21 – 23
Workshop on Recent Developments in Astrophysics (Celebration of International Year of Astronomy - 2009), at Tezpur University, Assam

November 3 – 6
National Workshop on Advances in Astronomy and Astrophysics, at Kashmir University, Srinagar

November 19 – 23
Introductory Workshop on Astronomy and
Astrophysics, at Panjab Univesity, Chandigarh

November 17 – 18
Mini-Workshop on European and Indian Approaches to Calculus, at IUCAA

November 23 – December 5
Global Stone Sculputure Workshop, at IUCAA

December 4
IUCAA-NCRA Graduate School First semester ends

December 8 – 10
Mini-Workshop on CMB Related Research at IUCAA

December 21 – 29
Second Radio Astronomy Winter School
(for College/University Students)
(Jointly by IUCAA and NCRA), at IUCAA / NCRA

December 29
Foundation Day

2010

January 4
IUCAA-NCRA Graduate School Second semester begins

January 13 – 14
Workshop on Astrophysics and Cosmology
at Calcutta University, Kolkata.

February 14 – 17
International Conference on Library Information Services in Astronomy (LISA – VI)
(Jointly with other Astronomy Institutes in India)
at IUCAA

February 28
National Science Day

ACADEMIC PROGRAMMES

The following description relates to research work carried out at IUCAA by the Core Academic Staff, Post-doctoral Fellows, and Research Scholars. The next section describes the research work carried out by Visiting Associates of IUCAA using the Centre's facilities.

(I) RESEARCH BY RESIDENT MEMBERS

Quantum Theory and Gravity

Gravity in higher dimensions and its universal features

Gravity is universal in the sense that it links to all particles whether massive or massless. It is the linkage to the latter, which demands that it can only be described by the curvature of spacetime. This means its dynamics must entirely be governed by the curvature and that it does through the Bianchi derivative of the Riemann curvature tensor. It turns out that the trace of the Bianchi derivative, in fact, yields the divergence free second rank symmetric tensor as the second order differential operator on the left hand side of the equation of motion. It was previously shown by **Naresh Dadhich** that it was not only true for the Einstein gravity, which is linear in Riemann curvature, but also for the quadratic Gauss-Bonnet, and in general, for Lovelock gravity, where the analogue of Riemann is a homogeneous polynomial in Riemann.

Thus, Bianchi derivative yielding the second order quasilinear differntial operator in the equation of motion for all orders in Riemann curvature is a universal feature of gravity. The question arises, is there any other such universal feature? The obvious property that comes to mind is gravity inside a uniform density fluid sphere. The Newtonian potential at any r will go as M/r^{d-3} for d dimensional spacetime. For uniform density sphere, M will go as r^{d-1} and so the potential will always go as r^2 in all dimensions > 3. This is an universal feature, which is independent of spacetime dimension. Will this feature carry over to the non-linear Einstein and Lovelock gravity? It turns out that it does and that is what has been proved recently by **Dadhich,** Alfred Molina and Avas Khugaev. The gravitational field of uniform density fluid sphere is described by the Schwarzschild's interior solution in the Einstein theory where the equivalent Newtonian potential goes as expected as r^2. It also remains true for all $d \geq 4$ in the Einstein gravity as well as for the Gauss-Bonnet and in general for the Lovelock gravity.

They have proved a theorem: The necessary and sufficient condition for universality of gravity (being true for Einstein and Einstein-Lovelock, and for all dimensions greater than 3) is that the fluid density is constant.

Maulik Parikh and **Sudipta Sarkar** have shown that all diffeomorphism-invariant theories of gravity appear to originate from thermodynamics. **Parikh** has also shown that the addition of a topological term to the gravitational action can greatly enhance the instability of four-dimensional de Sitter space and finally has shown that the smooth initial conditions that supply our universe's arrow of time can be obtained from weakening gravity in the early universe.

Holography in action

It is well-known that the Einstein-Hilbert action can be separated into a bulk term and a surface term. The bulk term depends on the metric and its first derivatives and is quadratic in the latter; the surface term arises from integrating a total divergence and contains both the normal and tangential derivatives of the metric on the boundary. Because of the dependence of the surface term on the normal derivatives of the metric, the action principle cannot be formulated in the usual manner. In general, the issue is handled in two ways:

(a) One can add an extra term to the Einstein-Hilbert action such that the variation of this term precisely cancels the unwanted terms arising in the variation of the original surface term.

(b) One can simply ignore the surface term in the Einstein-Hilbert action and vary the bulk term keeping the metric fixed at the boundary; even though the bulk term is not generally covariant, the resulting field equations are indeed covariant.

In either approach, it is *only* the variations of the bulk $\Gamma\Gamma$ term that contribute to the field equations. That is, the field equations (and their solutions) do *not* depend in any way on the surface term. It is, therefore, a mystery – in the conventional approach – that the surface term, which is ignored while obtaining the field equations, is actually equal to the entropy associated with the horizons which arise in specific solutions of the field equations!

This mystery was resolved by **T. Padmanabhan** in 2002, who showed that the bulk and surface terms in Einstein-Hilbert action are connected by a peculiar holographic relation, which allows the information about either one to be extracted from the other. **Padmanabhan** also showed that one can obtain the bulk action from the surface term if one adopts the thermodynamic perspective of gravity. Later on in 2006, these ideas were generalized to a wide class of models including the Lanczos-Lovelock models by *A. Mukhopadhyay* and **Padmanabhan**. The relationship between the bulk and boundary terms in the action was termed 'holographic' because the information about the bulk action functional (varying which, we can obtain the dynamical equations) is encoded in the boundary action functional.

The holographic nature of the action fits very well with the thermodynamic approach to gravity and can be thought of as the hidden signal in the action functionals indicating that the description of gravity is an emergent one. In fact, one can provide very general arguments to suggest that the action functional describing *any* theory of gravity that obeys the principle of equivalence and principle of general covariance will have a bulk and boundary term related holographically. If this is the case, one would like to explore this connection further and see what insights it can provide. In particular, one would like to address the following concrete questions:

(a) Of the two terms — bulk and boundary — the boundary term has a clear interpretation as being related to the entropy of horizons. But the physical interpretation of the bulk term is unclear and one would like to have a thermodynamic interpretation for the same.

(b) One would like to know whether there is something special in the particular decomposition of the Einstein-Hilbert action so that it admits a holographic relationship. Or can the holographic relationship arise in other contexts when we decompose the Einstein-Hilbert action into a bulk and surface term in a different manner ?

It turns out that the answers to these two questions are closely related. In a recent paper, **Sanved Kolekar** and **Padmanabhan** have shown that there is an alternate way of decomposing the action functionals in the case of static geometries which gives simple thermodynamic interpretation to both bulk and boundary terms as energy and entropy respectively. More specifically, the surface term becomes Wald entropy on a horizon and the bulk term is the energy density (which is the ADM Hamiltonian density for Einstein gravity). More importantly, this decomposition is also holographic, so that one can extract the information about the energy from entropy and vice-versa. It is in this context that the holographic structure of the action acquires a thermodynamic interpretation. Since the bulk and surface terms, in this decomposition, are related to energy and entropy, the holographic condition can be thought of as analogous to inverting the expression for entropy given as a function of energy $S = S(E, V)$ to obtain the energy $E = E(S, V)$ in terms of the entropy in a normal thermodynamic system. Thus, the holographic nature of the action allows one to relate the descriptions of the same system in terms of two different thermodynamic potentials.

The 'Avogadro number' for the atoms of spacetime

A simple example of an emergent phenomenon in physics is the dynamics of a fluid or the elastic properties of a solid. Many of the phenomena in fluid mechanics can be understood in terms of dynamical equations involving the density, velocity, etc. which are well-defined when the fluid is treated as a continuum. However, it has been known that the real fluid is made of discrete molecules with empty space in between. The macroscopic variables like density, velocity, etc. have no microscopic significance and certainly cannot be used to understand the microscopic physics of molecules making up the fluid. In this description, one thinks of fluid mechanics as an emergent phenomenon with its own dynamical variables and corresponding equations of motion that are valid at scales much bigger than the typical intermolecular separations.

Analogously, one could imagine the description of spacetime in terms of the metric, curvature, etc. as an emergent phenomenon valid at scales large compared to some critical length scale, which is likely to be the Planck length. It is then conceivable that the general theory of relativity is similar to the description of, say, fluid mechanics. Variables like the metric, etc. (being analogous to the density, velocity, etc. in fluid mechanics) have no significance in the microscopic description of spacetime. Just as the proper description of molecules of a fluid requires introduction of new degrees of freedom and a theoretical formalism (based on quantum mechanics), the microscopic description of spacetime will require the introduction of new degrees of freedom ('atoms of spacetime') and a theoretical formalism. These new degrees of freedom, and the theoretical framework, could be widely different from the description based on the metric, etc. just as the quantum description of molecules is quite different from that of a fluid based on density, velocity, etc. In that case, quantization of the metric itself is not of use in unraveling the microscopic structure of spacetime, any more than quantizing the density and velocity of a fluid will help us to understand molecular dynamics.

As first stressed by Boltzmann, the heat content of a fluid arises due to random motion of discrete microscopic structures, which must exist in the fluid. These new degrees of freedom, which are now known to be related to the actual molecules, make the fluid capable of storing energy internally and exchanging it with the surroundings. Given an apparently continuum phenomenon which exhibits temperature, Boltzmann could infer the existence of underlying discrete degrees of freedom. It has been known that the horizons, which arise in general relativity are endowed with temperatures. This shows that, at least in this context, some microscopic degrees of freedom are coming into play.

T. Padmanabhan and his collaborators have been involved in developing such a formalism over the last eight years, which could be considered as a 'top-down' approach to quantum structure of spacetime. Recently, **Padmanabhan** could develop these ideas further and show that the microscopic degrees of freedom obey a principle of equipartition in static geometries *in a wide class of theories of gravity* generalising a result originally obtained for Einstein gravity in 2004. It should be stressed that Boltzmann's equipartition law, $E = (1/2)NkT$ is a direct link between the microscopic degrees of freedom and macroscopic physics. The E and T in this relation can be defined in the continuum limit of thermodynamics but N has no meaning in thermodynamics, in which it is infinite! The finite value of N contains information about the statistical mechanics. Remarkably enough, one can prove an identical relation in the case of a general class of gravitational theories and read off N, which is like determining the Avogadro number of spacetime! Two striking consequences emerge from this analysis are as follows:

First, in the case of thermodynamics of normal systems [like for e.g., a gas] the number of degrees of freedom N scales as volume. In the case of gravity, *it can be proved* that N scales as the area of the boundary surface of any given volume! This again brings to the mind the holographic nature of gravity **Padmanabhan** has stressed in several previous papers.

Second, the surface density of degrees of freedom contains information about the theory of gravity one is dealing with. In the case of Einstein gravity, this surface density of 'atoms of spacetime' is a constant with one degree of freedom per Planck area. In other models, like Lanczos-Lovelock models, this gets modified by a factor proportional to $P^{ab}_{cd}\epsilon_{ab}\epsilon^{cd}$ where P^{ab}_{cd} determines the theory and ϵ_{ab} is the binormal to the boundary surface. One can show that this modification will correctly reproduce the known horizon entrpy for solutions in Lanczos-Lovelock models. In a way, specifying the suface density, determines the theory.

It is gratifying that the idea of gravity being an emergent phenomenon could be pursued to much deeper level than previously achieved and an equipartition law for the atoms of spacetime can be established.

Response of Unruh-DeWitt detector with time-dependent acceleration

One of the key results which have emerged from the study of quantum field theory in non-inertial coordinate systems is that both the particle content of the quantum states, as well as the pattern of vacuum fluctuations, are not generally covariant. This can be explicitly demonstrated by studying the response of detectors linearly coupled to the quantum field (usually called Unruh-DeWitt detectors) in different states of motion. It is well known that a detector, coupled linearly to a quantum field and accelerating through the inertial vacuum with a constant acceleration g, will behave as though it is immersed in a radiation field with temperature $T = (g/2\pi)$. When the trajectory $X^i_*(\tau)$ is along the integral curve of a time-like Killing vector field in flat spacetime (we will call such trajectories 'stationary'), the Wightman function G^+ will only depend on the time difference u. In this case, the transition rate which involves an integral over time t will lead to a divergent result. This is handled by the usual procedure of time dependent perturbation theory, which involves ignoring the integral over t and interpreting the rest of the result as providing the rate of transitions between the two levels. For the stationary trajectories, this rate will be a constant. The previously mentioned uniformly accelerated trajectory, in fact, corresponds to the integral curve of the Killing vector field corresponding to Lorentz boost along the direction of the acceleration g. In this particular case, the pattern of vacuum fluctuations match with the particle content of the quantum state and the rate of excitation of the detector will correspond to a thermal spectrum of particles with a temperature $T = g/2\pi$. This is of particular importance, because it allows us to associate a temperature with the Rindler horizon with obvious implications for black hole physics.

Unfortunately, a detector which is uniformly accelerated from $\tau = -\infty$ to $\tau = +\infty$ is not physically realizable. The question arises as to what happens in the case of more realistic detectors. One possible way of addressing this question is to keep the coupling to the field switched on only for a finite interval of time. But this introduces transients and one needs to handle them with care. It also does not seem very natural to switch off the coupling in this manner. A more obvious and physically interesting way of attacking the problem would be to study the response of a detector moving along a given direction with a time-dependent acceleration $g(\tau)$.

There are atleast three further motivations for taking up this study which are somewhat indirect. First, we know that there is a direct correspondence between the detector response in a uniformly accelerated trajectory and the phenomena which takes place in the Hartle-Hawking vacuum state around a black hole. By extending this analogy, we would expect a sub-class of time-dependent accelerations — especially those $g(\tau)$ which vanish at early times and become constant at late times — to correspond to the phenomena which takes place in a collapsing black hole scenario in the Unruh vacuum state. Second, there has been considerable amount of work in recent years, which attempts to interpret the field equations of gravity as a thermodynamic identity. This body of work uses the concept of local Rindler observers that corresponds to trajectories which, in the local inertial frames around any given event, will be a hyperbola. While one expects such a local concept to be valid as a first approximation, it is important to verify it explicitly. Finally, this subject has thrown up fair number of surprises and subtleties in the past and one cannot take it for granted that intuitively obvious results will arise when we rigorously analyse the case of, say, a slowly varying acceleration! It requires explicit verification. Our naive expectation will be that, for sufficiently slowly varying acceleration (with $(\dot{g}/g^2) \ll 1$) one would expect the detection rate to correspond to a time dependent temperature $T(\tau) \propto g(\tau)$. At the same time, one will *not* expect such a result to hold for all frequencies of the thermal spectrum. There is, in fact, a good reason to expect some modification due the presence of (local acceleration) horizon. This sets a length scale g^{-1} in the problem, which can be compared with the length scale probed by a particular mode, ω^{-1}. Of course, we know that the spectrum is Planckian for all values of $g^{-1}\omega$ when g is constant; it is, therefore, interesting to see whether a varying g makes any difference.

In a recent paper, **Dawood Kothawala** and **T. Padmanabhan** have addressed the issue of detector response for rectilinear motion with slowly varying acceleration with the aim of clarifying some of the above issues. After defining the rate of excitation of the detector appropriately, they have evaluated this rate for time-dependent acceleration, $g(\tau)$, to linear order in the parameter $\eta = \dot{g}/g^2$. Their result demonstrates an interplay between the three length scales in the problem: g^{-1}, $(\dot{g}/g)^{-1}$ and ω^{-1} where ω is the energy difference between the two levels of the detector at which the spectrum is probed. They have shown that: (a) When $\omega^{-1} \ll g^{-1} \ll (\dot{g}/g)^{-1}$, the rate of transition of the detector corresponds to a slowly varying temperature $T(\tau) = g(\tau)/2\pi$, as one would have expected. (b) However, when $g^{-1} \ll \omega^{-1} \ll (\dot{g}/g)^{-1}$, we find that the spectrum is modified *even at the order* $O(\eta)$. This is counter-intuitive because, in this case, the relevant frequency does not probe the rate of change of the acceleration since $(\dot{g}/g) \ll \omega$ and we certainly do not have deviation from the thermal spectrum when $\dot{g} = 0$. This result shows that there is a subtle discontinuity in the behaviour of detectors with $\dot{g} = 0$ and $\dot{g}/g^2$ being arbitrarily small. They have further corroborated this result by evaluating the detector response for a particular trajectory which admits an analytic expression for the poles of the Wightman function.

Gravitational Waves

Gravitational wave astronomy: A new window

Gravitation is the most dominant interaction on the large scale. Matter on a large scale is electrically neutral and it is gravity that dominates and plays a major role in the dynamics of astronomical systems. The past several decades have shown a great revolution in astronomy. Optical, radio, X-ray, γ-ray, and infrared astronomies have yielded enormous information about the universe and brought about vital changes in our understanding of the universe. The above mentioned astronomical windows have brought forth surprises which have crucially supplemented our knowledge of the universe. To mention a few, some of the important discoveries were, the cosmic microwave background, pulsars, quasars, γ-ray bursts visible from large distances, dark energy, etc. None of these discoveries were anticipated by the observers, because the instruments were built mainly to observe completely different phenomena. Another window to the universe is now in the offing - that of gravitational waves (GW). A direct detection of gravitational waves will not only test Einstein's theory of relativity in the strong field regime, but also pave the way to observing exotic objects in the universe. The direct observation of black holes and the measurement of their parameters will go towards testing the important theorems about them, which were discovered almost half a century ago.

Gravitational waves have, thus, a great potential for springing surprises on us. This is because the gravitational interaction is so different from the electromagnetic interaction. Gravitational waves are produced by bulk motion of matter at long wavelengths and will essentially carry information complementary to that of electromagnetic waves. Because of the weak coupling of gravitation to matter, GW are not easily scattered and carry high fidelity information about the source. On the downside, this also makes them hard to detect. Given that less than 5 % of the matter in the universe carries a charge, GW are the right probe to observe the rest of the universe, which is the major component.

Gravitational wave detectors measure not only the amplitude of the incident GW but also the phase. The information about the source is encoded also in the phase. Thus, the data analysis methods for extracting the GW signal are usually different from that of conventional astronomy. Since one must use the phase information in the signal, the GW detection methods rely more strongly on the theoretical models of the GW sources than that encountered in other branches of astronomy.

During the past decade or so, many ground based detectors have begun initial operations. These are the LIGO (US), VIRGO (France-Italy), GEO (Germany-UK) and TAMA (Japan). There are also plans to build future ground-based detectors in Australia (AIGO) and LCGT in Japan. India is also planning on a GW experiment called IndIGO. The initial LIGO detector has surpassed its goal sensitivity, solidly establishing the credibility of the Ligo Science team and gravitational wave science. However, the initial design sensitivity of LIGO is still an order of magnitude away from the envisaged sensitivity at which one expects to detect GW. This sensitivity is expected to be achieved by advanced detectors, which are underway and should begin operating in this decade. The best sources for these detectors are coalescences of compact binaries - neutron stars/black holes. At IUCAA, the extraction of GW inspiral signals of compact binaries has been the main focus of research for several years.

Apart from the ground-based detectors, there are plans also to build detectors in space. The Laser Interferometric Space Antenna (LISA) is a proposed space mission of the ESA and NASA to observe low frequency GW in the range 0.1 mHz to 0.1 Hz. The signals for LISA are expected to be from merging massive and supermassive black holes, vibrating black holes, relatively smaller mass objects falling into massive and supermassive black holes. Since the masses involved are large, the signals come with high signal to noise ratios, from which detailed and accurate information can be extracted. The detailed information can be used to test general relativity in the strong field regime.

(i) Coincidence versus coherent search for gravitational waves from inspiraling binaries.

Inspiraling binaries are one of the most promising sources for the first detection of GW. The post Newtonian approximation methods accurately describe the phasing of the waveform - about a cycle in a wave train $\sim 10^4$ cycles long. This makes them amenable for matched filtering analysis. The best available estimates suggest that at 1% false alarm probability, the expected number of neutron star -

neutron star binary coalescences seen per year by ground based interferometers is $3 \times 10^{-4} - 0.3$ for initial detectors and $1 - 800$ for advanced detectors. In recent years, a number of ground based detectors are producing sufficiently interesting sensitive data and analysis of network data is imminent. The advantages of multi-detector search for the binary inspiral is that, not only does it improve the confidence of detection, it also provides directional and polarisational information about the GW source.

Two strategies currently exist in searching for inspiraling binary sources with a network of detectors: the coherent and the coincident. The coherent strategy involves combining data from different detectors phase coherently, appropriately correcting for time-delays and polarisation phases and obtaining a single statistic for the full network, that is optimized in the maximum likelihood sense. On the other hand, the coincident strategy matches the candidate event lists of individual detectors for consistency of the estimated parameters of the GW signal. However, the phase information is ignored and also the detectors are considered in isolation.

The question arises as to which strategy performs better. On simple waveforms the analysis has been performed by Finn and Arnaud. Both these works have shown that the coherent strategy performs better than the coincident strategy. H. Mukhopadhayay, **S. Dhurandhar**, H. Tagoshi and N. Kanda have considered the astrophysically important source, namely, the inspiraling binary for the realistic case of geographically separated detectors. In previous works by the same authors, the case of coaligned detectors in the same place was considered. The strategies are compared by plotting the *Receiver Operating Characteristic* (ROC) curves, which is the plot of detection efficiency versus the false alarm rate.

The *naive* coincident strategy treats the detectors as if they are isolated - compares individual detector statistics with their respective thresholds while looking for consistency in the estimated parameters of the signal. When the detectors are taken to be widely separated on Earth, and since the detector arms must lie parallel to the Earth's surface, the detectors almost necessarily have different orientations. In this situation, the naive coincidence strategy leads to poor coverage of the sky resulting in unacceptably large false dismissal. To circumvent this problem the *enhanced* coincidence strategy has been proposed. The enhanced coincidence strategy is intermediate in the sense, that though the individual statistics are added in quadrature and the sum compared with a single threshold, the estimated parameters are also checked for consistency. For simplicity, detector pairs having the same power spectral density of noise, as that of initial LIGO are considered and also the noise is assumed to be stationary and Gaussian. Since the detectors are geographically separated, uncorrelated noise is a justifiable assumption. Simulations are performed in order to plot the ROC curves. A single astrophysical source as well as a distribution of sources is considered. One year data train and a mass range of $1 - 40 M_\odot$ is taken for the case of astrophysically distributed sources. It is found that the coherent strategy is still superior to the two coincident strategies that are considered. Remarkably, the detection probability of the coherent strategy is 50% better than the naive coincident strategy. On the other hand, the difference in performance between the coherent strategy and enhanced coincident strategy is not very large. The bottom line is that the coherent strategy is a good detection strategy.

It is, however, felt that for real data, the coincidence strategy acts as a powerful veto to rule out non-Gaussian noise and, thus, fake events. In coincidence detection, the requirement of the consistency of estimated parameters in an error window acts as a powerful veto, to weed out fake events generated from non-Gaussian noise. On the other hand in coherent detection as yet no such obvious veto has been developed. This, however, does not rule out the possibility that a powerful veto cannot be constructed for the coherent strategy. This will form the main thrust of future work of the team.

(ii) Time-delay interferometry for LISA

LISA - Laser Interferometric Space Antenna - is a proposed ESA-NASA mission, which will use coherent laser beams exchanged between three identical spacecraft forming a giant (almost) equilateral triangle of side 5×10^6 kilometres to observe and detect low frequency cosmic GW.

Laser frequency noise dominates the other secondary noises, such as optical path noise, acceleration noise by 7 or 8 orders of magnitude, and must be removed if LISA is to achieve the required sensitivity of $h \sim 10^{-22}$, where h is the metric perturbation caused by a gravitational wave. In LISA, six data streams arise from the exchange of laser beams between the three spacecraft approximately 5 million km apart. These six streams produce re-

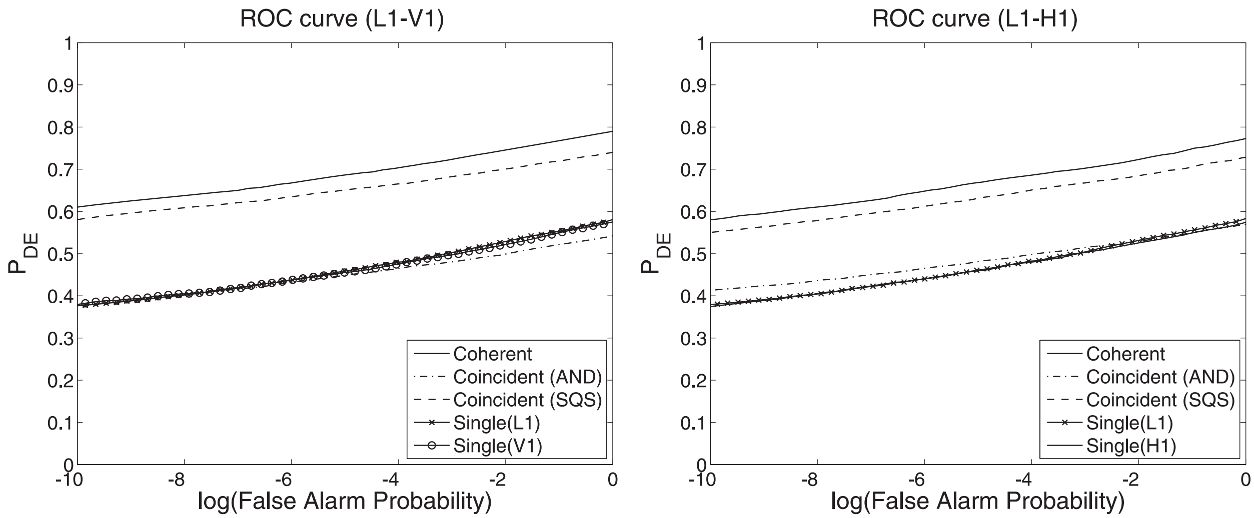


Figure 1: The ROC curves have been plotted for coherent, naive coincidence and enhanced coincidence for uniformly distributed sources. The left figure is drawn for the LIGO, Livingston and Virgo pair of detectors, while the right figure corresponds to the LIGO Livingston and LIGO Hanford detector pair.

dundancy in the data which can be used to suppress the laser frequency noise by the technique called time-delay interferometry (TDI) in which the six data streams are combined with appropriate time-delays. A mathematical foundation for the TDI problem for static LISA was given previously by **Dhurandhar** and collaborators, where it was shown that the data combinations cancelling laser frequency noise formed the *module of syzygies* over the polynomial ring of time-delay operators. For static LISA, the polynomial ring was in three variables and also commutative. The generators of the module were obtained via Gröbner basis methods. This scheme could be extended in a straight forward way to include the (Sagnac) effect arising from the rotation of LISA, where the up-down optical links are unequal. Now there are six optical links, but the armlengths are still constant in time. The polynomial ring is still commutative although now over six indeterminates. These are the modified Ist generation TDI. In the general case of time varying armlengths, the polynomial ring is in six variables (the six optical links) but now it is non-commutative. There is still a linear system which leads to a module (a left module), but it seems difficult to obtain its generators in general. In the non-commutative case, it is possible that the the Gröbner basis algorithm does not terminate, leading to an infinite Gröbner basis. Thus, the solution to the general algebraic problem seems extremely difficult.

Dhurandhar, R. Nayak and J-Y Vinet have investigated the case when one of LISA's arms is dysfunctional. One must envisage the possibility that not all optical links of LISA will be operating at all times for various reasons like technical failure, for instance, or even because of high operating costs. Therefore, it is important to discuss the question when not all the links operate. A specific situation is investigated, where the data is available from only two arms or four optical links. This should not much affect the information that can be extracted from the data, because this is essentially a Michelson configuration which is known to be quite useful. The practical advantage for this case is that the algebraic problem simplifies considerably and, therefore, becomes tractable. The problem can be reduced to that of only one linear constraint on two polynomials, although the equation is still non-commutative. **Dhurandhar** and collaborators have shown that an infinity of solutions can be generated using a combinatorial algebraic approach, which lists all such solutions in a systematic way. The solutions - that is, the laser frequency noise is suppressed for these time-delayed data combinations - are approximate in the sense that higher order terms are ignored in the calculation. The solutions are based on vanishing commutators. Such commutators are listed and enumerated, and for each such commutator there is a corresponding solution. An algorithm is presented to construct such solutions.

The algebraic approach has the advantage of easy manipulation of data streams and yields a rich family of second generation TDI solutions. The analysis can be used also for other future space detectors like ASTROD, where again the mathematical problem is identical.

(iii) A fast transform for periodic waves from pulsars and rotating neutron stars.

The all sky all frequency search for pulsars or rotating neutron stars is an extremely computionally intensive problem. The reason for this is that, the signal is very weak and requires long integration times of the order of a few months to build up significant signal to noise ratio. In this period of time, the detector executes complex motion as it is carried by the rotating and revolving Earth. Thus, if the source direction and frequency of the source is unknown one must demodulate the signal for each direction and then search over the frequency. In a simple model in which the source is assumed to be monochromatic, a Fourier transform after the demodulation can be performed to reveal the signal. Even in this simple case for a year worth of data over a kHz bandwidth, one must search over 10^{13} directions leading to 10^{24} computer operations! This simple model does not account for the intrinsic spindown of the pulsar. Including the spindown parameters would escalate the computational cost further by few orders of magnitude.

Several schemes involving alternately coherent and incoherent stages of data processing have been developed but they do not come anywhere near solving the problem - that is, perform the data analysis with the current computer resources in real time. **Dhurandhar** and B. Krishnan from AEI, Potsdam, Germany, have come up with a completely different approach based on group theory. The idea is to exploit the symmetries in the problem to reduce the computational cost. The procedure sought is analogous to the procedure followed in the fast Fourier transform. In the simple case of one circular motion of the detector, say, the Earth's motion around the Sun, the group essentially turns out to be the Euclidean group in the plane. In the general case, the three dimensional translation group plays the corresponding role. But the idea would be to identify an appropriate subgroup of this larger group. The *stepping around the sky* approach of Schutz seems to be useful in formulating the problem. This work is being done under the Ligo Science Collaboration.

A brief description of the detailed problem is as below. Consider a 'barycentric frame' in which the isolated neutron star is at rest or moving with uniform velocity. Ignoring spindowns, the signal in this frame is assumed to be a pure sinusoid. First, the simple case of one circular motion is considered. The signal at the detector is not a pure sinusoid but is modulated by the Doppler correction due to the motion of the detector carried by the Earth. The Doppler correction depends on the direction to the source relative to the motion of the detector. In this case, the demodulation over the azimuth can be performed very efficiently by using the fast Fourier transform, that is, in order of $B \log_2 B$ operations, where B is the number of frequency bins the signal is spread into by Doppler modulation. Typically, for $N \sim 10^8$ frequency bins, $B \sim (v/c)N \sim 10^4$, where v is the velocity of the Earth in the barycentric frame and $v/c \sim 10^{-4}$. The brute force method on the other hand leads to order of B^2 operations. A similar approach could be applied to search over the polar angle. Here, it may be possible to use Bessel function identities based on group theory to save on computational costs. One could also think of extending the method to spindown parameters. The results so far obtained seem encouraging and one expects this approach to yield rich dividends.

Cosmology and Structure Formation

Effect of a 'Mini-Waterfall' during inflation on the Cosmic Microwave Background

The great precision of current cosmological data and the enormous volume of data expected in coming years leads to the hope that cosmological parameters will soon be determined to great accuracy. Since cosmological parameters are intimately linked to an underlying theoretical model, the increasing depth and sophistication of cosmological data sets, especially those associated with the Cosmic Microwave Background (CMB), will, in all likelihood, lead to a more refined and deeper understanding of such important issues as the form of the initial perturbation spectrum, the energy scale of inflation, etc.

Minu Joy, **Varun Sahni** and Alexei Starobinsky have explored an important issue concerning the form of the primordial spectral index $n_s(k) \equiv d \ln P(k)/d \ln k$. The large quantity of CMB data, which has become available over the past few years indicates that the departure of the spectral index from exact scale invariance is likely to be small, $|n_s(k) - 1| \ll 1$, which is in good agreement with predictions of the simplest inflationary scenarios. An associated question concerns the value of the running of the spectral index $\alpha(k) \equiv d\,n_s(k)/d \ln k$. Most inflationary models with smooth inflaton potentials do predict a non-vanishing value of $\alpha(k)$, usually $|\alpha(k)| \sim |n_s(k) - 1|^2 \ll 1$. However, recent WMAP results may be suggesting a somewhat larger value $|\alpha(k)| \sim |n_s(k) - 1|$. Taken together with other 'anomalies' such as the 'Archeops feature' at $l \sim 40$, these recent data may be providing a subtle hint that inflationary models are slightly more complex than the simplest single-field models suggested during the early 1980's.

The only way for a large value of the running $\alpha(k)$ to be accommodated within the inflationary paradigm is for it to be localized (i.e., have the form of a *feature*), since, otherwise, the number of inflationary e-foldings turn out to be too small. They have focussed on an exact solution for the primordial scalar perturbation spectrum generated during inflation discovered in an earlier paper in which the effective mass of the inflaton, $V''(\phi)$, experiences a sudden small change during inflation.

The resulting inflationary perturbation spectrum possesses a local universal feature having the form of a step in the primordial spectral index n_s, modulated by comparatively weak oscillations (by universal, it is meant that the form of the spectral feature does not depend upon the structure of the discontinuity in $V(\phi)$). It results in a large (but local) running of n_s, as shown in Figure 2.

The simplest microscopic realization of such behaviour of $V(\phi)$ is provided by a model having an auxiliary heavy scalar field, which experiences a rapid second order phase transition (a mini-waterfall) during inflation in the observably accessible range of scales. Coupling this field to the inflaton leads to the desired type of local discontinuity in $V(\phi)$. The model is similar to that used in the hybrid inflationary scenario, but in contrast to the latter, its parameters are chosen in such a way that: (i) the transition occurs during inflation and not at its end, (ii) the change in the inflaton mass is small compared to the Hubble parameter at this moment. That is why we call it a 'mini-waterfall', in contrast to a 'waterfall', which ends inflation in the hybrid scenario.

The authors have found that the best χ^2_{eff} for this model shows an improvement by 3.052 over the best fit obtained assuming a featureless power law for the primordial spectrum; see Figure 3. Consequently, a 'mini-waterfall' during inflation is not excluded by the present observational data. Better data expected from future CMB experiments will help to settle the question about its existence.

Is cosmic acceleration slowing down ?

One of the most tantalising observational discoveries of the past decade is that of the *accelerating* universe. This discovery now has support from a number of distinct data sets including observations of high redshift Type Ia supernovae, Baryon Acoustic Oscillations (BAO) in the large scale distribution of galaxies and fluctuations in the Cosmic Microwave Background (CMB). **Varun Sahni** , Arman Shafieloo and Alexei Starobinsky have investigated the nature of cosmic acceleration by analysing the recently released 'Constitution' data set consisting of almost four hundred Type Ia supernovae, treated as standard candles, and covering a redshift range from $z_{min} = 0.015$ to $z_{max} = 1.551$.

Their results (which came as a surprise to them as well as the larger cosmology community) indicated that the equation of state of dark energy (DE) may be evolving. Indeed, a question which lies uppermost in the minds of most theorists studying DE is whether its properties evolve with time or remain unchanging. While most astrophysical quantities show some evolution with time, the enigmatic *cosmological constant*, introduced by Einstein in 1917, does not evolve. Therefore, one of the primary concerns of any test of the DE hypothesis would be to distinguish the properties of DE from those of the cosmological constant on the basis of cosmological observations. This was the aim behind the introduction of the Om diagnostic by the above authors in 2008. Om is defined as follows:

$$Om(x) \equiv \frac{h^2(x) - 1}{x^3 - 1}, \quad x = 1 + z\,, \; h(x) = H(x)/H_0,$$

where $H \equiv \dot{a}/a$ is the expansion rate of the universe and $a(t)$ is its expansion factor.

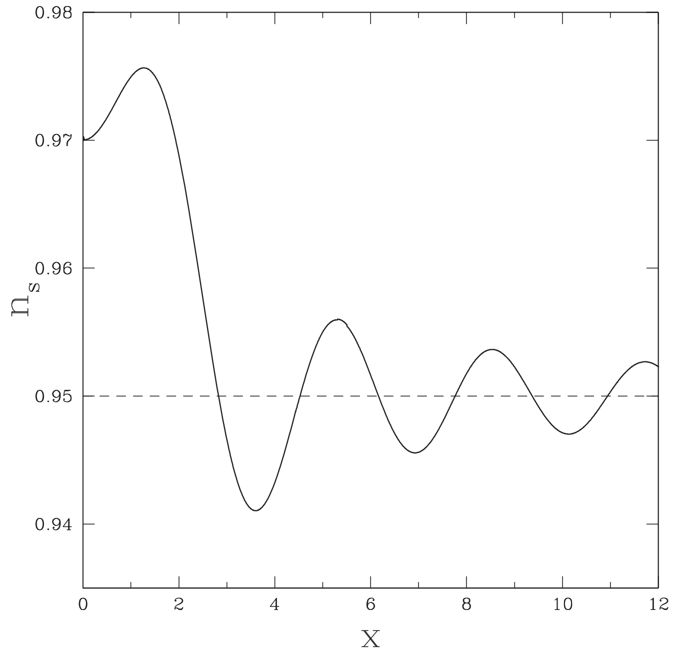


Figure 2: A step in the second derivative of the inflaton potential leads to a step in the spectral index as shown in this figure, which plots the primordial spectral index n_s as a function of $x = k/k_0$. The step in n_s at $x \sim 1$ is followed by oscillations with decreasing amplitude. The parameters shown here correspond to $n_1 = 0.97$, $n_2 = 0.95$, which agree well with WMAP5 data.

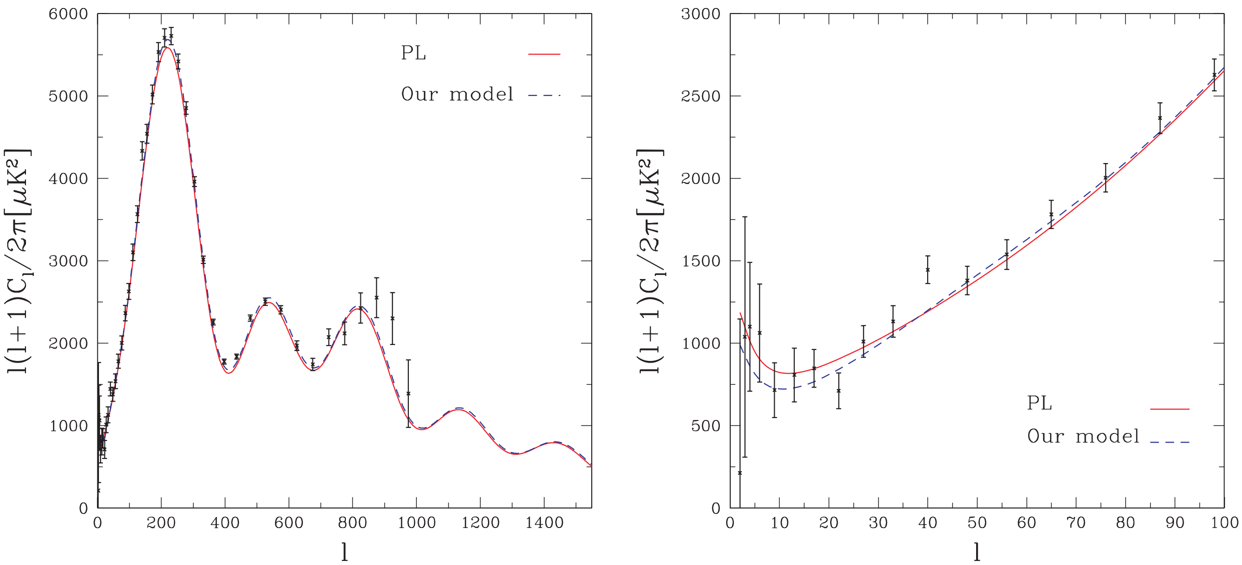


Figure 3: Comparison of our model (blue, dashed) with a pure power-law model (red, solid), for the best fit values of parameters. The WMAP5 binned data with related error bars are also plotted for comparison.

Remarkably, the Om diagnostic provides us with a *null test* of the cosmological constant since $Om(z) = \Omega_{0m}$ only for the Λ-term. For other dark energy models the value of $Om(z)$ is *time-dependent*, as shown in Figure 4.

Varun Sahni , Shafieloo and Starobinsky have applied the Om diagnostic to recent observations of Type Ia supernovae, BAO and CMB. Their results show that theoretical models in which dark energy evolves with time fit the observational data very well.

An indication that dark energy might be evolving is reflected in the Om diagnostic which *increases* at redshifts $z \lesssim 0.3$ (see Figure 5). This figure shows that evolving DE appears to fit the data better than the cosmological constant (for which the value of Om remains fixed, as shown in figure 4).

This suggests that cosmic acceleration may have already peaked and that we are currently witnessing its slowing down. The case for evolving DE strengthens if a subsample of the constitution set consisting of SNLS+ESSENCE+CfA SN Ia data is analysed in combination with BAO+CMB using the same statistical methods.

One can also probe cosmic acceleration directly, using the deceleration parameter $q = -\ddot{a}/aH^2$, so that $q > 0$ corresponds to deceleration wheareas $q < 0$ corresponds to *acceleration*. The value of this important quantity is shown in Figure 6 for SNLS+ESSENCE+CfA SN Ia data analysed in combination with BAO+CMB data. In a universe dominated by the cosmological constant, the value of $q(z)$ monotonically decreases towards -1 as the universe accelerates. By contrast, Figure 6 appears to indicate that the value of $q(z)$ is currently *increasing*, which is indicative of a slow-down of cosmic acceleration.

The effect we observe could correspond to DE decaying into dark matter (or something else). On the other hand, there could also be another reason for the observed effect: namely that the systematics in some of the data sets is not sufficiently well understood. For instance, if nearby Type Ia supernovae are systematically brighter than those further away, then they could no longer be used as standard candles. Ongoing and future work by different teams on the properties of Type Ia supernovae and their correlation with host galaxies is likely to shed some light on this important issue.

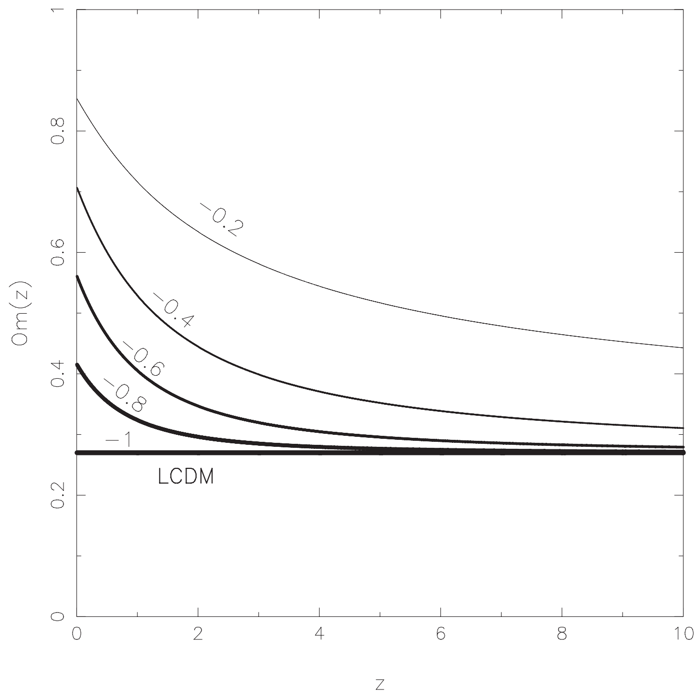


Figure 4: The Om diagnostic is shown as a function of redshift for DE models with $\Omega_{0m} = 0.27$ and $w = -1, -0.8, -0.6, -0.4, -0.2$ (bottom to top). LCDM (equivalently ΛCDM) indicates the cosmological constant for which $w = -1$ and the value of Om does not evolve.

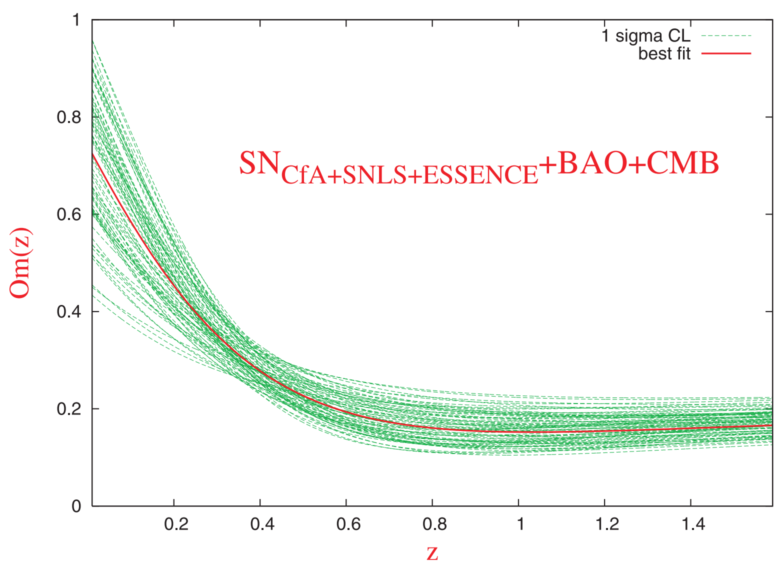


Figure 5: The Om diagnostic is reconstructed from SN Ia + BAO + CMB data. Solid red lines show the best fit values of $Om(z)$, while dashed green lines show the 1σ CL. Note the strong evolution in the best fit $Om(z)$ at low z.

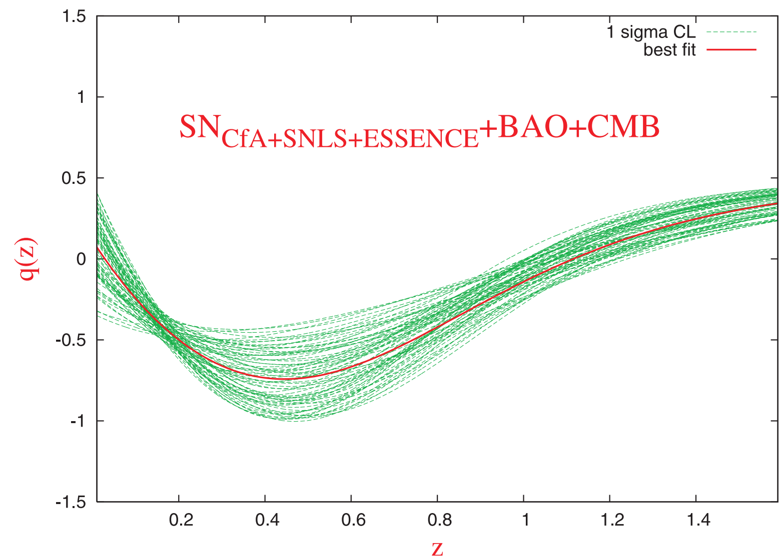


Figure 6: The deceleration parameter is reconstructed from SN Ia + BAO + CMB data. Solid red lines show the best fit values of $Om(z)$, while dashed green lines show the 1σ CL. Note that the universe appears to have accelerated more rapidly in the past ($z \sim 0.5$) than at present ($z = 0$).

Distinguishing between rival dark energy models using standard candles and rulers

The next decade will see the emergence of many new cosmological experiments carrying important implications for the properties of dark energy. These will include the Sloan Digital Sky Survey and its Baryon Oscillation Spectroscopic Survey (BOSS), the Joint Dark Energy Mission (JDEM), which is expected to determine the luminosity distance to great precision, etc. In addition, the Square Kilometer Array (SKA) will map out over a billion galaxies to redshift of about 1.5, and is expected to determine the power spectrum of dark matter fluctuations as well as its growth as a function of cosmic epoch. Important clues to the growth of structure will also come from current and future weak lensing surveys, galaxy redshift-space distortions, etc. With the wealth of data expected to arrive over the next several years, it is important to find different methods of analyzing these datasets in order to extract the optimum amount of information from them. Ujjaini Alam, **Varun Sahni** and Alexei Starobinsky have discovered a new method of reconstructing the linearized growth rate of density perturbations in the non-relativistic matter component, $\delta(z)$, from datasets, which have traditionally been used to explore only the smooth background universe, e.g. , luminosity distance data (from standard candles) and angular diameter distance data (from standard rulers). Their approach can furnish useful information about the properties of dark energy and help to distinguish models such as the cosmological constant and quintessence from rival models in which, cosmic acceleration is caused by infrared modifications of general relativity (prominent examples include Braneworld models and $f(R)$ gravity theories).

Ujjaini Alam, **Sahni** and Alexei Starobinsky have made the important observation that linearized matter density perturbations can be directly determined from an integration of the luminosity distance, which is *a sound operation for noisy data.* Since the luminosity distance is related to the angular-size distance very simply, this allows us to determine the density contrast from standard candles (high redshift Type Ia supernovae) or standard rulers (BAO). Furthermore, the precision with which the luminosity distance is known is likely to improve considerably over the coming years as new standard candle/ruler data sets (such as those expected from JDEM), become available. Consequently, the ansatz of Ujjaini Alam, **Sahni** and Alexei Starobinsky can be used to distinguish dark energy models in which the universe accelerates due to modified gravity from those in which cosmic acceleration is caused by dark energy. This is illustrated in Figure 7.

Evolution of shocks and turbulence in major cluster mergers

Galaxy groups and clusters are the largest virialized objects to have arisen in the process of cosmic structure formation. These structures assemble via an hierarchical clustering of matter driven by gravity. The large scale distribution of matter in the universe resembles a 'cosmic-web' structure of interconnected network of large filaments, voids, and sheets of galaxies, where clusters form at the nodes of this matter distribution. How such complex structures arise from the primeval density fluctuations has been an enduring quest. The cosmic shock waves, which are produced by accretion and halo mergers play an important role in the process of hierarchical structure formation, yet their origin and their contribution in the thermal and non-thermal processes in clusters is not very well understood. Major cluster mergers, where the mass ratio of the infalling halos approaches unity, are among the most energetic events of the universe; the energy release from a merger of two clusters of mass $10^{15}\ M_{\odot}$, moving with ~ 1000 km s^{-1} relative to each other, may approach 10^{64} erg.

Previous numerical simulations make a distinction between two classes of shocks, namely the "internal" and "external" shocks. The former group indicates weaker (Mach number $\mathcal{M} < 5$) shocks found in the hot ICM resulting from merging events, whereas the latter ones are generated by the infall of cold unprocessed baryons on accreting structures, thus producing shocks with stronger temperature gradients and consequently larger Mach numbers ($\mathcal{M} > 10$). Both external and internal shocks dissipate a large fraction of kinetic energy in the ICM. Strong astrophysical shocks are also capable of producing high energy cosmic-ray particles (CR) via diffusive shock acceleration (DSA) mechanism. These shocks, thus, have been proposed as potential acceleration sites of the ultra relativistic CR particles emitting the observed non-thermal radio emission in clusters. Some fraction of cosmic γ-ray background may also be generated by these shock accelerated particles through inverse-Compton scattering of the Cosmic Microwave Background Radiation.

The compression at the shocks may lead to first-order Fermi acceleration (Fermi I), whereas the turbulent energy in the post-shock region can partly be transferred to the CR by the second-order Fermi acceleration mechanism (Fermi II) or stochastic acceleration. Merger shocks are particularly interesting for the injection of volume-filling turbulence in the ICM. If a turbulent flow is established in the ICM, turbulent dissipation acts on a significantly longer timescale than shocks. Turbulence can in principle re-accelerate the ambient electrons and amplify weak magnetic fields by the dynamo action. This makes it possible to see the shocks also in radio, due to the radio-synchrotron emission from accelerated charged particles in such an amplified magnetic environment. A latest cosmological simulation work in this area has been carried out by **Joydeep Bagchi** and **Surajit Paul**, in collaboration with Luigi Iapichino (Heidelburg Univ., Germany), Francesco Miniati (ETH, Zurich, Switzerland) and Karl Mannheim (Wurzburg Univ., Germany). The simulations were carried out at the Munich University's LRZ (Leibniz-Rechenzentrum) Supercomputing Facility at Garching, Germany, on the SGI Altix 4700 *HLRB-II* supercomputer.

They performed a series of cosmological simulations of structure formation using the Adaptive Mesh Refinement (AMR), grid-based hybrid (N-body plus hydrodynamical) code 'Enzo'. A flat ΛCDM background cosmology was adopted with parameters $\Omega_{\Lambda} = 0.7$, $\Omega_{\rm m} = 0.3$, $\Omega_{\rm b} = 0.04$, $h = 0.7$, $\sigma_8 = 0.9$, and $n = 1$. The simulation box has a comoving size of 128 Mpc h^{-1} on a side. The simulations have been initialized at redshift $z = 60$ and evolved upto to $z = 0$. Grid refinement from levels $l = 0$ (root grid) to $l = 6$ (finest grid) were enabled. An ideal equation of state was used for the gas, with $\gamma = 5/3$. Cooling physics and feedback were neglected, because they play only a minor role in the merger problem that was investigated. Furthermore, neglecting cooling processes imply that the simulated virialized objects obey self-similar scaling laws. This turns out to be useful as it allows to extrapolate results obtained for the modest mass simulated objects ($M \simeq 10^{14}\ M_{\odot}$) to the more massive and actually observed structures. The focus of their study was on specific merger events, which occurred at $z < 0.7$ and between halos with mass $M > 10^{13}\ M_{\odot}$ at the time of merger. As a criterion for selecting only major (binary) mergers, events with a mass ratio between the two merging clumps $\Delta_{\rm m} > 0.5$ were only included. Since shocks are associated with flows with negative divergence

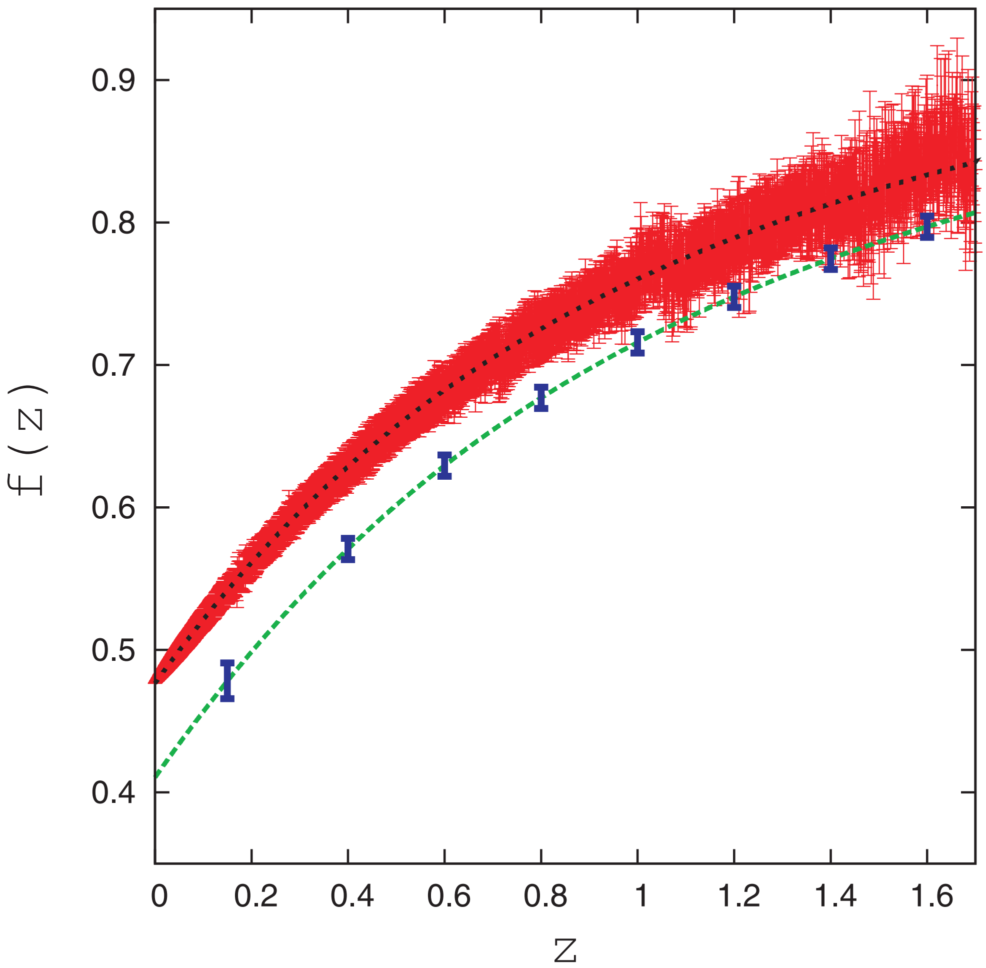


Figure 7: Reconstructed growth rate $f(z)$ for JDEM-like supernova dataset using the DGP braneworld model in which the universe accelerates due to *modified gravity*. The green dashed line represents the result expected from gravitational clustering in the DGP model. The red solid lines show the 1σ error bars for the integral reconstruction which implicitely assumes that dark energy is quintessence-like. The blue vertical lines show the expected observational constraints from the Euclid experiment. The discrepancy between the thick black dotted line and the green dashed line would be a 'smoking gun' signal for modified gravity.

of the velocity field, they used an AMR criterion based on the local variability of the rate of compression of the flow (the negative time derivative of the divergence $d = \nabla \cdot \mathbf{v}$).

The morphological evolution of structures in a typical merger event is shown in Figure 8. Two subclumps approach each other with a relative velocity of 980 km s^{-1}, collided for the first time at $z \simeq 0.3$ (Figure 8*c* left panel) and then pass through a core oscillation phase. The merging cores are still distinctly visible at least until $z = 0.1$ (Figure 8*g* left panel) before the final coalescence at $z = 0.05$. The web-like network of filaments is also clearly visible around the forming structure.

The most prominent effect during a cluster merger is the evolution of the baryonic component, whose energy budget is significantly altered by the event. The gas in the ICM is severely attracted in the forming potential well, eventually generating a shock wave which propagates through the intracluster gas of the newly formed cluster. Part of the kinetic and gravitational energy of the merger event is, thus, dissipated into the ICM. This crucial feature of mergers is better followed by the evolution of temperature (Figure 8, right panels). The temperature increase is first driven by compression at the centre of the forming cluster (right panels 8*a* to 8*c*), and subsequently the shock is launched and propagated outwards. It can be followed in the simulation even after it covers few virial radii from the cluster centre (at $z = 0$, $R_{\rm vir} = 1$ Mpc h^{-1} for the cluster shown). The maximum temperature in the cluster region exceeds 10^8 K at $z = 0.2$, several times larger than the cluster virial temperature (about 3×10^7 K).

The shape of the emerging shock depends on the mass of the merging clumps and on the geometry of the merger. The shock front has a roughly ellipsoidal shape, with the shock arcs more pronounced along the merger axis. The propagation velocity of the shock is initially up to 1500 km s^{-1} and only slightly decreases in time with the expansion of the shock. They have computed the Mach number $\mathcal{M}$ of the two most prominent shock arcs, to the left and to the right with respect to the cluster centre, by applying the Rankine-Hugoniot jump conditions. Between $z = 0.25$ and 0.15, $\mathcal{M}$ is in the range between 2.5 and 7.0. The larger values are reached for the arc on the right-hand side of the panels in Figure 8, resulting in a mild asymmetry. As this shock propagates out of the ICM of the newly formed cluster, it interacts with the surrounding filaments. For the first time, it is revealed in their simulations that the interaction with the web-like cosmic structure of filaments and voids causes the fragmentation of the merger shock in separate sections, as clearly visible by comparing the bottom rows of Figure 8. This interesting feature is obviously not modeled so far in simulations of idealized mergers, where symmetric bow-like shocks propagates unimpeded outwards.

The development and propagation of a large scale shock is a remarkable consequence of the hierarchical growth of halos undergoing major mergers. Besides the already described effects for the morphology, the energetics and the heating of the ICM in the simulation work, the injection and evolution of turbulence in the post-shock region was also studied in great detail. Velocity fluctuations are a distinctive feature of turbulent flows. It is, therefore, straightforward to relate the generation of turbulence with the production of vorticity occurring at curved shock, expressed by the curl of the Euler's equation :

$$\frac{\partial \omega}{\partial t} = \nabla \times (\mathbf{v} \times \omega) - \frac{\nabla p \times \nabla \rho}{\rho^2},$$

where the second term at the right-hand side is non-vanishing in curved shocks.

This theoretical expectation is confirmed by their simulations. In the reference run, significant amount of vorticity is produced after the merger, just behind the shock, and propagates along with it. This process is shown in Figure 9: some level of vorticity is clearly associated to both clumps before merging (Figure 9*a*) and also to the centre of the newly formed cluster (Figure 9*i*), but the magnitude of ω tracks markedly the generation of turbulence in the post-shock region (for $z < 0.2$, Figures 9*e* to 9*i*). Different from minor mergers, in the case under consideration, a simple visual inspection of Figure 9 suggest that major mergers stir the ICM effectively, resulting in a very volume-filling production of turbulence. In Figure 9, one notes that the values $\omega \gtrsim 5 \times 10^{-17}$ s^{-1} correspond, according to the standard definitions, to a vorticity parameter (representing the number of local eddy turnovers) $\tau \gtrsim 10$, namely to a relatively large vorticity and to a full developed turbulence. In agreement with theoretical expectations, such high values of ω are reached in the ICM after the merger, as well as in the post-shock region. The size of the post-shock region along the direction of shock propagation is of the order of 300 kpc h^{-1},

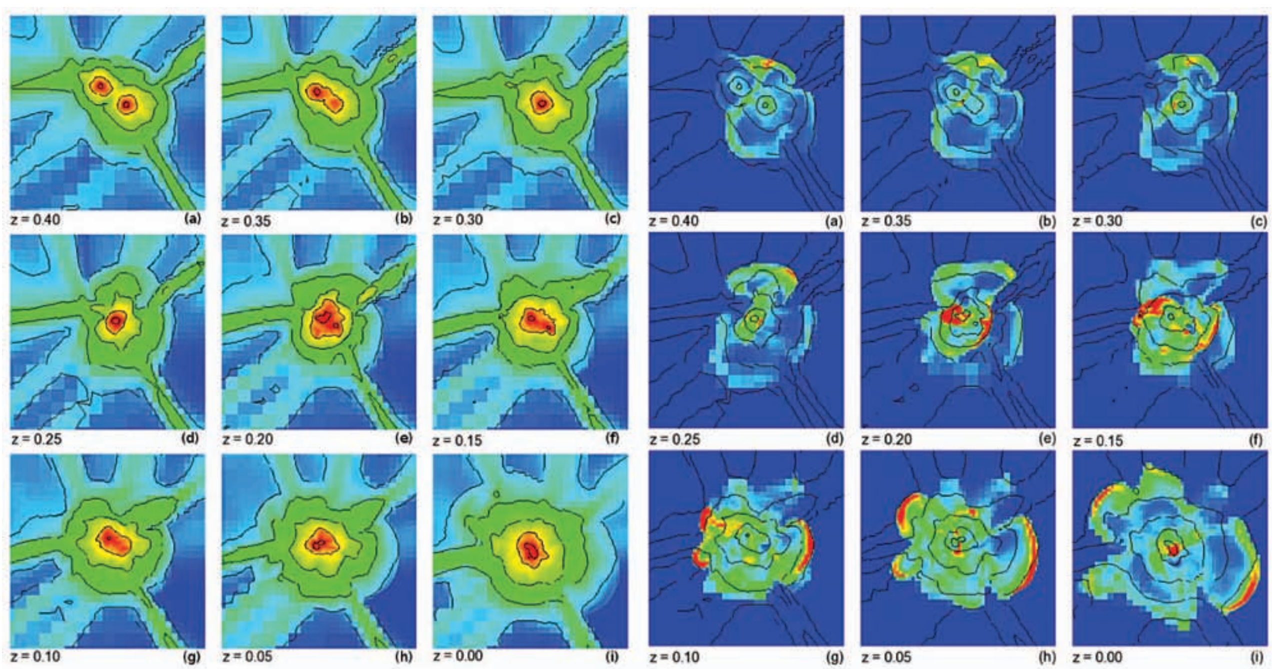
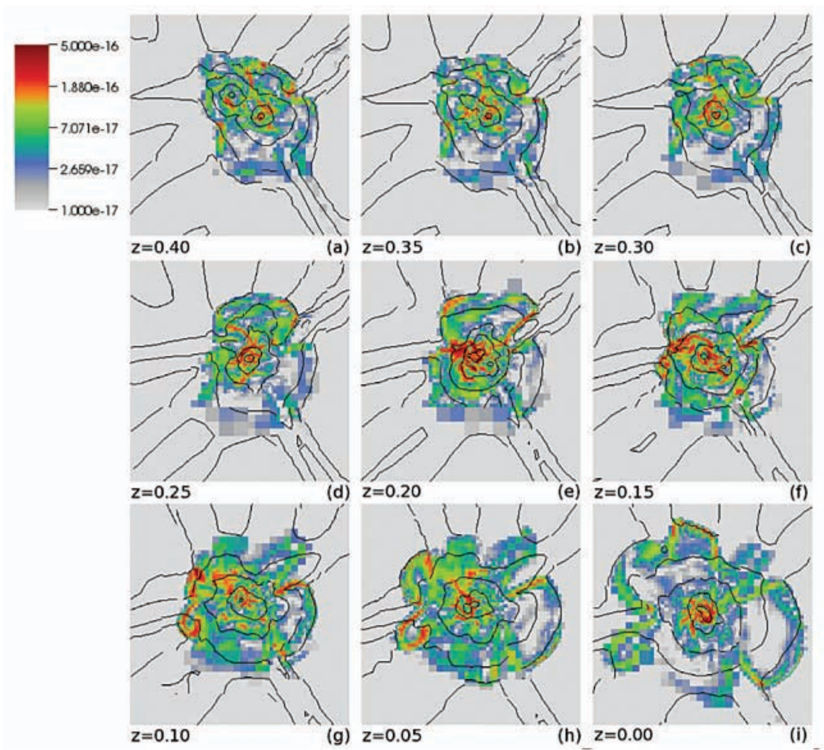


Figure 8: Left hand 9 panel group: Redshift evolution of a representative cluster merger event is shown in density slices. The redshift is indicated at the lower left of each panel. Each panel has a size of 7.7×7.7 Mpc h^{-1} and is parallel to the y-z plane of the simulation volume. Baryon density is colour coded, and also represented by contours. Right hand 9 panel group: Same as the left panels, but here ICM temperature is shown colour coded, with density contours overlayed. The highest temperature level of the scale (red) is set to 3.8×10^7 K, but the central temperature may be $\sim 10^8$ K in some panels. The maximum temperature behind the shock fronts goes beyond 5×10^7 K.



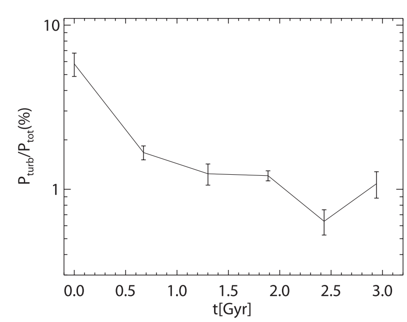


Figure 9: Left hand 9 panel group: Redshift evolution of a representative cluster merger event is shown in density slices. The redshift is indicated at the lower left of each panel. Each panel has a size of 7.7×7.7 Mpc h^{-1} and is parallel to the y-z plane of the simulation volume. Baryon density is colour coded, and also represented by contours. Right hand 9 panel group: Same as the left panels, but here ICM temperature is shown colour coded, with density contours overlayed. The highest temperature level of the scale (red) is set to 3.8×10^7 K, but the central temperature may be $\sim 10^8$ K in some panels. The maximum temperature behind the shock fronts goes beyond 5×10^7 K.

and the turbulent velocity dispersion in this region is larger than 100 km s^{-1}. As for the turbulence in the cluster core, it is found that within 2 Gyr after the major merger (the timescale for the shock propagation in the ICM), the ratio of the turbulent to total pressure in core is larger than 10%, and even after about 4 Gyr, it is still larger than 5%, a typical value for nearly relaxed clusters (Figure 9). Thus, contrary to expectations, it is shown that turbulence at the cluster centre is sustained for several Gigayears, which is substantially longer than typically assumed in the turbulent re-acceleration models, invoked for explaining the statistics of observed Mpc-scale radio halos in clusters.

Cosmic Microwave Background

As regularly reported in previous annual reports, **Tarun Souradeep**, his students, and collaborators, have maintained a successful research programme related to the CMB anisotropy and polarization.

The CMB anisotropy and polarization measurements continue to contribute handsomely to the rapid pace of progress in cosmology. Increasingly more attention is being paid to emerging avenues of fruitful research on subtle cosmic signatures, often referred to as 'CMB anomalies'. The most recent data released by the Wilkinson Microwave Anisotropy Probe (WMAP) team in January 2010 devotes a separate paper to the CMB anomalies and have invoked the bipolar representation of Amir Hajian and **Souradeep** to quantify them. In the past year, **Souradeep** and collaborators have published further studies on the origin and characterization of the subtle signatures of statistical isotropy violation in the CMB sky maps.

Tuhin Ghosh, **Souradeep** and collaborators have continued to make progress on model independent extraction of the diffuse galactic foreground emission that contaminates the cosmic signal, as well as, the primary CMB angular spectra of anisotropy and polarization.

Souradeep and collaborators have also carried out careful analysis of the significance of features in primordial power spectrum (PPS) suggested by the direct recovery by Arman Shafieloo and **Souradeep**. In collaboration with L. Sriramkumar's group at HRI, **Moumita Aich** has studied a suite of inflation models that produce features in PPS and over the past year, these have been pitted against current CMB measurements.

Statistical isotropy of the CMB sky

As reported in previous annual reports, Bipolar Spherical Harmonic (BipoSH) representation has been proposed and established by the group. **Tuhin Ghosh**, Rajib Saha, Pankaj Jain and **Tarun Souradeep** recently published the first, completely model independent estimate of the foreground contamination to the CMB maps from the diffuse galactic emission. During a CEFIPRA visit to Paris in October 2009, **Ghosh** embarked on a project with Jacques Delabrouille at APC to produce from the WMAP data the 'best' model free maps of the foreground emission at the five WMAP frequencies ranging from 22-94 GHz. Figure 10 illustrates the steps in this approach at one of the frequencies (K band:23 GHz). The method involves estimating the achromatic CMB signal employing NILC – wavelet (needlet) space internal linear combination developed by Delabrouille, et al. earlier. This CMB signal estimate is then removed from the WMAP maps at different frequencies. Finally, the different maps are Wiener filtered to suppress the noise contribution to provide reliable foreground emission maps at the WMAP frequencies. The galactic (foreground) emission maps at the CMB frequencies are expected to provide very useful information about galactic physics, as well as help in cleaner extraction of the CMB signal in upcoming experiments.

IUCAA associate *Sanjay Jhingan* and his student, Nidhi Joshi, together with **Souradeep** and Amir Hajian have published a comprehensive study relating the bipolar observables to stepwise symmetry breakdown of statistical isotropy to smaller symmetry sub-groups. With bipolar representation of SI violation finding progressively wider usage in the community, in particular, by the WMAP team, this analysis provides the required understanding of SI violation (symmetry breakdown) measurements and constraints expressed in terms of the bipolar observables to reveal the physics behind their origin.

The CMB anisotropy and polarization power measured at all angular scales arise from free-streaming of anisotropy power at very low multipoles (essentially, the monopole, dipole and quadrupole) in the baryon-photon plasma at the epoch of last scattering. **Moumita Aich** and **Souradeep** have published a complete formalism to relate violation of statistical isotropy in the photon distribution function at the last scattering surface to non-zero bipolar coefficients in the present observed CMB. As an illustrative example, they have demonstrated that this formalism provides an elegant understanding of statistical isotropy violation due to a homogeneous magnetic field in the baryon-photon plasma. Currently, they are applying this formalism to understand other symmetry breaking physical effects in the baryon-photon plasma.

As reported in previous annual reports, **Souradeep**, Saha and Jain, have developed a novel method of estimating the angular power spectrum from multi-frequency data that evades the modeling uncertainties involved in template based methods that use extraneous foreground maps measured by different instruments at very disparate frequency bands. Subsequently, a lot of effort has gone into extending the method to extract the WMAP CMB polarization spectra leading to a Iinternal power spectrum estimation (IPSE) method. The challenge has been to overcome the limitation posed by the WMAP sensitivity (noise level relative CMB polarization signal). The collaboration, now including Simon Prunet, Jacques Delabrouille, and Saha have published an independent estimate of the CMB polarization spectra (EE & TE) from WMAP 5 year data shown in Figure 11.

Ghosh and **Souradeep** have developed, and now implemented, DAPSE – an improved method that employs a clever strategy to alleviate the bias arising in IPSE due to the co-dominance of foregrounds and noise on intermediate angular scales. This allows a more robust estimation of the CMB polarization power spectra from the WMAP seven year data. As a next step, **Ghosh** will explore the feasibility of applying the methods developed here in the analysis of data from the recently launched Planck Surveyor mission.

Early universe from CMB

As reported in previous annual reports, the accurate measurements of the angular power spectrum over a wide range of multipoles from the WMAP allowed Arman Shafieloo and **Tarun Souradeep** to deconvolve the primordial power spectrum from the angular power spectrum of CMB anisotropy measured by WMAP. In the absence of a preferred model of inflation, it is important to assess the significance of any features obtained. Together with Jan Hamman, Shafieloo and **Souradeep** have published a frequentist analysis of the the significance of features obtained by direct deconvolution. This complements Bayesian approaches used by others, and evades issues inherent to the Bayesian approach arising due to the absence of an appropriate, well-defined, model space.

In collaboration with L. Sriramkumar's group at HRI, **Moumita Aich** has carried out careful analysis of scenarios of inflation that led to features in PPS favoured by data. The collaboration has compared the CMB predictions of a suite of models with the currently available CMB measurements from experiments such as WMAP, ACBAR and QUaD.

As reported last year, the punctuated inflation model proposed earlier by the collaboration provides a very good fit to the WMAP data. These predictions have now been compared to observations that include the other CMB data sets. Besides providing a better fit to data, the punctuated inflation scenario brings to the fore new aspects in the understanding of inflationary predictions, in particular, the possibility of suppression or enhancement of perturbations on scales well after they have exited the Hubble radius. **Gaurav Goswami** has carried out a careful study to distill the salient aspects of mode evolution that come into play in these phenomena. The modes that have once frozen in amplitude and phase after being stretched to super-Hubble radius scales can be made to undergo a short phase of evolution even while they are super-Hubble radius scale, to another frozen state. These features, arising due to super-Hubble scale evolution, have been elegantly explained through a key, robust condition that the super-Hubble scale modes are constrained to evolve along an incoming radial trajectory in the complex plane. Hence, they can attain very small values, leading to super-Hubble suppression, if they freeze close to the origin, as well as undergo super-Hubble enhancement, if they evolve past the origin to a larger magnitude than the initial freeze out. Interestingly enough, if any mode evolves past the origin, then the radial evolution demands that there exists a wavenumber for which, the amplitude of the scalar perturbation mode is exactly frozen at zero amplitude!

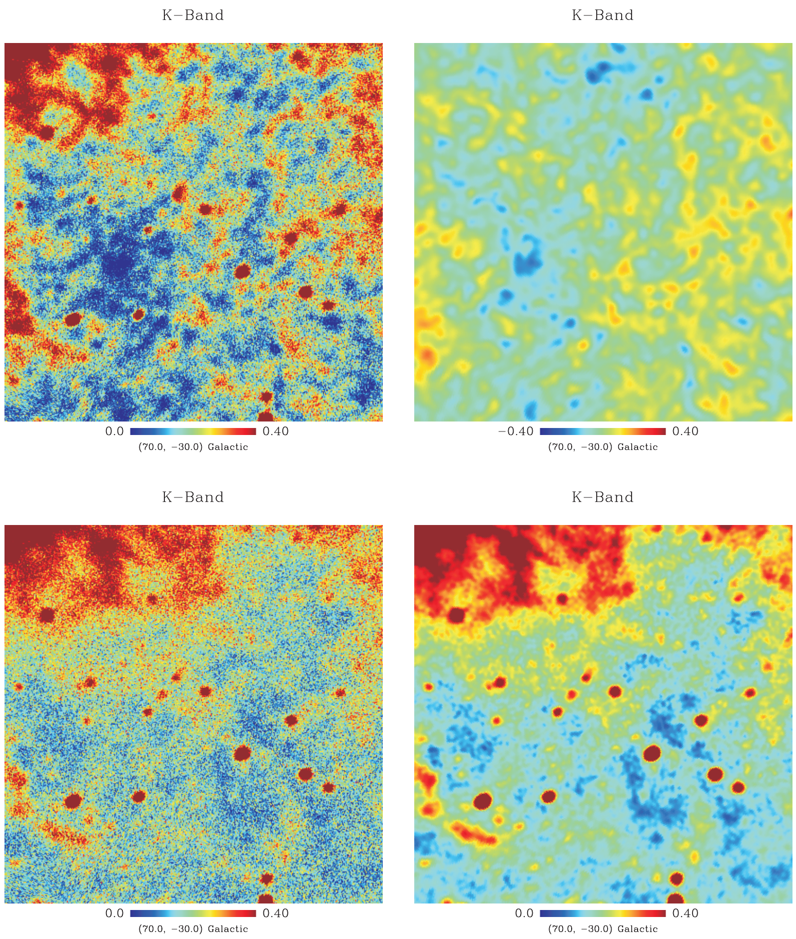


Figure 10: **Diffuse galactic foreground emission map from WMAP :** The four maps over a patch of the sky at K band (23 GHz) illustrate the steps in the method employed by **Tuhin Ghosh**, et al. at all the WMAP frequencies using a model independent approach. The *top-left* panel shows the observed WMAP map at the K-band. The *top-right* shows the CMB component extracted using needlet space internal linear combination (NILC) that needs to be removed from the observed map. The *bottom-left* map is the difference after CMB subtraction that contains foreground, as well as, noise that dominates at small angular scales. The noise causes the graininess and distorts compact features in the foreground emission. The *bottom-right* panel is the final foreground map recovered by Wiener filtering the difference map to suppress the noise contribution. The clarity of the foreground emission, including small compact structures is evident in the final map.

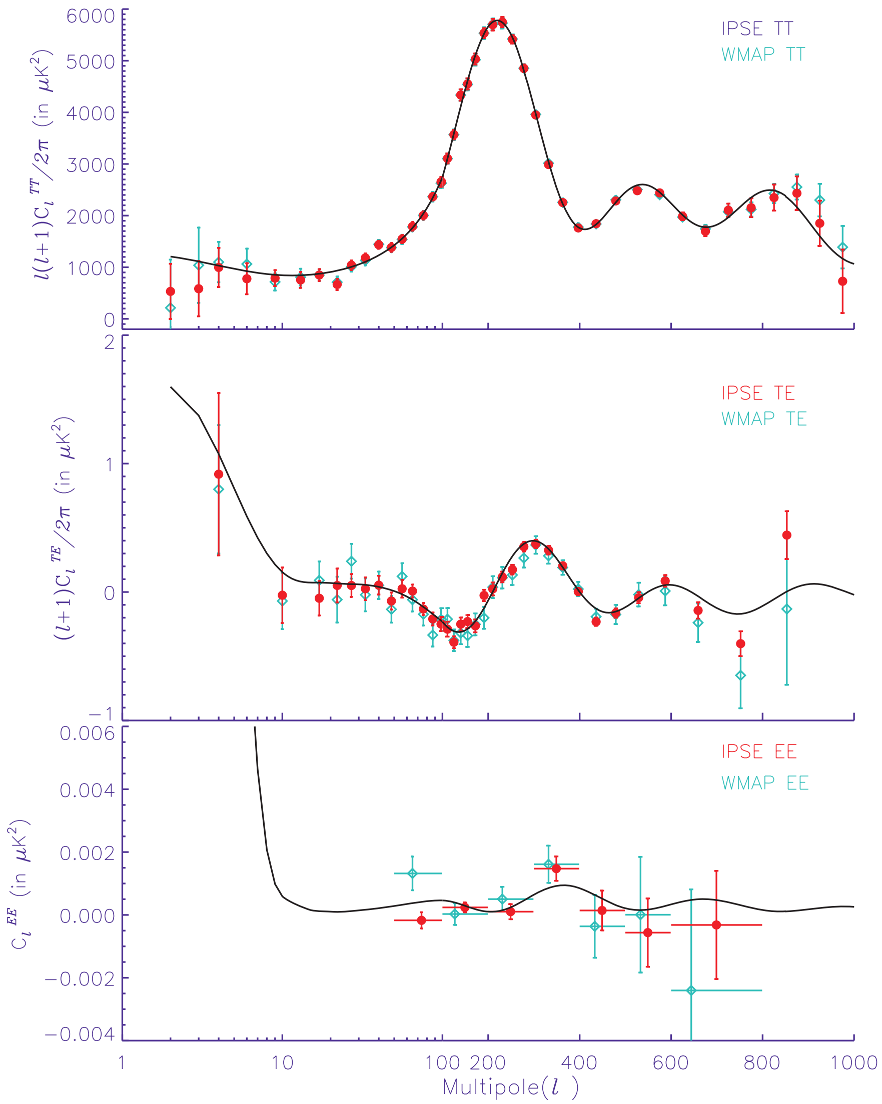


Figure 11: **CMB angular power spectra from WMAP using IPSE :** The CMB temperature (TT) and polarization (TE & EE) angular power spectra *sans foreground modeling* obtained by the Internal Power Spectrum Estimation (IPSE) method *[Samal, et al. ApJ, 2010]*. This independent confirmation of the angular power spectra from WMAP (5 year data) alleviates concerns due to uncertainties in our current understanding and modeling of the diffuse galactic foreground emission inherent in other approaches.

CMB bispectrum from primordial magnetic fields on large angular scales

Non-Gaussianity of the temperature anisotropy of the Cosmic Microwave Background (CMB) has recently aroused considerable interest in the context of inflationary models. Primordial magnetic fields lead to non-Gaussian signals in the CMB even at the lowest order, as magnetic stresses, and the temperature anisotropy they induce, depend quadratically on the magnetic field. In contrast, CMB non-Gaussianity due to inflationary scalar perturbations arise only as a higher order effect. *T.R. Seshadri* and **K. Subamanian** have proposed a novel probe of stochastic primordial magnetic fields that exploits the characteristic CMB nongaussianity that they induce. In particular, they have computed the CMB bispectrum ($b_{l_1 l_2 l_3}$) induced by stochastic primordial fields on large angular scales. They find a minimal value of $l_1(l_1+1)l_3(l_3+1)b_{l_1 l_2 l_3} \sim 10^{-22}$, for magnetic fields of strength $B_0 \sim 3$ nano Gauss and with a nearly scale invariant magnetic spectrum. Current observational limits on the bispectrum then allows them to set upper limits on $B_0 \sim 15 - 35$ nano Gauss.

Observational Cosmology and Extragalactic Astronomy

Models of high redshift luminosity functions and galactic outflows: The dependence on halo mass function

The form of the halo mass function is a basic ingredient in any semi-analytical galaxy formation model. **S. Samui, K. Subramanian and R. Srianand** have studied the existing forms of the mass functions in the literature and compared their predictions for semi-analytical galaxy formation models. Two methods are used in the literature to compute the net formation rate of halos, one by simply taking the derivative of the halo mass function and the other using the prescription due to Sasaki (1994). For the historically used Press-Schechter (PS) mass function, they compared various model predictions, using these two methods. However, as the Sasaki formalism cannot be easily generalized for other mass functions, they use the derivative while comparing model predictions of different mass functions.

They have shown that the reionization history and UV luminosity function of Lyman break galaxies (LBGs) predicted by the PS mass function differs from those using any other existing mass function, like Sheth-Tormen (ST) mass function. In particular the reionization efficiency of molecular cooled halos has to be substantially reduced when one uses the ST and other mass functions obtained from the simulation instead of the PS mass function. Using χ^2-minimization, they have found that the observed UV luminosity functions of LBGs at $3.0 \leq z \leq 7.4$ are better reproduced by models using the ST mass function compared to models that use the PS mass function. On the other hand, the volume filling factor of the metals expelled from the galaxies through supernovae driven outflows differs very little between models with different mass functions. It depends on the way they treat merging outflows. They have also showed that the porosity weighted average quantities related to the outflow are not very sensitive to the differences in the halo mass function.

Understanding the redshift evolution of the luminosity functions of Lyman-α emitters

Determining the star formation history of the high redshift universe is one of the major goals of ongoing observations. Available observational data mainly consists of UV luminosity functions (LFs) of high redshift Lyman break galaxies (LBGs), which can, in turn, give the star formation rate density of the universe. In addition to the 'drop-out' techniques, narrow band searches for high redshift galaxies emitting a strong Lyman-α line are successful in detecting galaxies at $3 < z < 6$.

S. Samui, R. Srianand and K. Subramanian have worked out a semi-analytical model of star formation which explains simultaneously the observed UV luminosity function of high redshift Lyman break galaxies (LBGs) and luminosity functions of Lyman-α emitters. They considered both models that use the Press-Schechter (PS) and Sheth-Tormen (ST) halo mass functions to calculate the abundances of dark matter halos. The Lyman-α luminosity functions at $z < 4$ are well reproduced with less than $\sim$ 10% of the LBGs emitting Lyman-α lines with rest equivalent width greater than the limiting equivalent width of the narrow band surveys. However, the observed luminosity function at $z > 5$ can be reproduced only when we assume that nearly all LBGs are Lyman-α

emitters. Thus, it appears that $4 < z < 5$ marks the epoch when a clear change occurs in the physical properties of the high redshift galaxies. As Lyman-α escape depends on dust and gas kinematics of the inter stellar medium (ISM), this could mean that on an average, the ISM at $z > 5$ could be less dusty, more clumpy and having more complex velocity field. All of these will enable easier escape of the Lyman-α photons. At $z > 5$, the observed Lyman-α luminosity functions are well reproduced with the evolution in the halo mass function along with very minor evolution in the physical properties of high redshift galaxies. In particular, upto $z = 6.5$, they do not see the effect of evolving intergalactic medium (IGM) opacity on the Lyman-α escape from these galaxies.

Cosmic ray driven outflows from high redshift galaxies

S. Samui, K. Subramanian and R. Srianand have studied winds in high redshift galaxies driven by a relativistic cosmic ray (proton) component in addition to the hot thermal gas component. Cosmic rays (CRs) are likely to be efficiently generated in supernova (SNe) shocks inside galaxies. They have obtained solutions of such CR driven free winds in a gravitational potential of the Navarro-Frenk-White (NFW) form, relevant to galaxies. Cosmic rays naturally provide the extra energy and/or momentum input to the system, needed for a transonic wind solution in a gas with adiabatic index $\gamma = 5/3$. They have shown that cosmic rays can effectively drive winds even when the thermal energy of the gas is lost due to radiative cooling. These wind solutions predict an asymptotic wind speed closely related to the circular velocity of the galaxy. Furthermore, the mass outflow rate per unit star formation rate (η_w) is predicted to be $\sim 0.2 - 0.5$ for massive galaxies, with masses $M \sim 10^{11} - 10^{12} M_\odot$. They show η_w to be inversely proportional to the square of the circular velocity. Magnetic fields at the micro Gauss levels are also required in these galaxies to have a significant mass loss. A large η_w for small mass galaxies implies that cosmic ray driven outflows could provide a strong negative feedback to the star formation in dwarf galaxies. Further, our results will also have important implications to the metal enrichment of the intergalactic medium. These conclusions are applicable to the class of free wind models, where the source region is confined to be within the sonic point.

Quasars probing intermediate redshift star-forming galaxies

The study of intervening absorption lines seen in the spectra of bright distant objects is one of the most sensitive and powerful probes for understanding the early evolution of galaxies. Indeed, at low and intermediate redshifts ($z \sim 1$), the connections between QSO absorption systems and galaxies are mainly investigated for Mg II-selected systems. These absorbers are found to be statistically associated with relatively bright field galaxies seen within a few tens of kpc to the QSO line of sight (see Bergeron 1991 and Steidel 1995). These studies established that Mg II absorbers provide an unbiased way to detect normal galaxies at different redshifts. However, the success rate of detecting Mg II absorption in the spectrum of QSOs that have known foreground galaxies with redshift measurements is much less than one (Bechtold, et al. 1992; Bowen, et al. 1995 and Tripp, et al. 2005). These studies suggest that the gaseous halos around galaxies may be less uniformly populated than what was thought before (see Kacprzak , et al. 2008). Also, it is not necessary that the galaxies responsible for Mg II absorption are always bright $L_\star$ galaxies.

It has also been proposed that other classes of QSO absorbers, such as those characterised by strong Ca II absorption lines, could select the most metal-rich gas (Wild , et al. 2006; Nestor, et al. 2008) hence, probing more central parts of high-redshift galaxies. Wild, et al. (2007) have statistically detected [O II] emission associated to strong Mg II- and Ca II-selected absorbers by stacking SDSS quasar spectra. However, only a few direct detections of emission lines from absorbing galaxies have been reported so far. Zych, et al. (2007) presented direct imaging and long-slit spectroscopic observations of five quasars with strong Ca II systems at $z < 0.5$. They have detected [O II], [O III], Hα and Hβ emission lines at the redshift of the absorbers. The luminosity of the corresponding galaxies is high, $L \simeq L_\star$, with star-formation rates in the range 0.3 - 30 $M_\odot$ yr^{-1}.

When galaxies are detected with some projected separation to the QSO sight-line, it is not obvious whether one is detecting the halo gas associated with the galaxy or one is probing the correlation length of metals in the IGM with respect to the bright galaxies. The contribution of possible faint galaxies closer to the line of sight (i.e., within the point spread function of the QSO) that remain undetected is also not well explored. Therefore, even after two decades of intense research activity to establish the Mg II absorber-galaxy relationship, there are still open questions in this field that need to be answered.

Taking advantage of the available ~100 000 fibre spectra of quasars in the Sloan Digital Sky Survey-II, DR7, **Pasquier Noterdaeme, R. Srianand and Vijay Mohan** have built a unique sample of 46 star-forming galaxies at $z < 0.8$ detected through their nebular ([O III] and/or [O II]) emission lines seen on top of the background quasar spectra (some examples are shown in Figure 12). They have shown that the detectability of [O III] lines is not biased by the luminosity of the background quasars. They have studied both the emission and absorption properties of a sub-sample of 17 galaxies at $z \geq 0.4$ for which, the expected positions of Mg II lines are covered by the SDSS spectra. The detections show that one is probing a unbiased population of low luminosity [O III]-emitting galaxies at small impact parameters (10 kpc; i.e., the SDSS fibre radius) from the quasar lines of sight. They have found that typical properties (metallicity, star-formation rates, and kinematics) of these galaxies are similar to that of normal star-forming galaxies at these redshifts. The low E (B-V) measured along the quasar lines of sight indicates that the absorption lines arise from regions relatively free of dust.

They have found that the equivalent widths of Mg II absorption lines arising from the [O III]-selected galaxies are skewed towards higher equivalent widths than the overall population of Mg II absorbers. However, the [O III]-selected Mg II absorbers represent only a small fraction of the overall Mg II population. From stacking the spectra of quasars featuring strong Mg II absorbers, they have detected the [O II] and [O III] emission lines. The average line fluxes are below our typical detection limit in individual spectrum. This suggests that at least part of the strong ($W(MgII) > 1$ Å) Mg II absorption systems arise from low luminosity galaxies at small impact parameters.

SDSS spectra allowed **Noterdaeme, Srianand** and Vijay Mohan to explore the possible connections between various parameters of the galaxies (such as metallicity, dust content and kinematics) derived from the absorbing gas and that derived from emission lines in a limited redshift range. Nevertheless, their representative sample of 46 galaxies is ideally suited for several follow-up observations using space and ground-based telescopes. This should allow one to explore various issues such as: the connection between the reddening along the QSO line of sight and the dust extinction in the line-emitting region; the comparison between the emission and absorption line metallicities; the dependence of the properties of the absorbing gas on the galaxy morphology, kinematics and impact parameter, etc. Finally, They have performed long-slit spectroscopic observations (from IUCAA Girawali Observatory) of the most luminous galaxy with Mg II absorption in their sample (SDSS J113108+202151). They have shown that the [O II] emission detected in the SDSS spectrum is not detected in the extended bright galaxy seen on the SDSS image (see Figure 13). This, once again, suggests that one should be cautious in associating intervening absorption (or emission) to bright galaxies seen in the field with photometric redshift measurements only.

SDSS J092712.64+294344.0: Recoiling black hole or merging galaxies?

The discovery of unresolved point sources with two sets of emission lines that are powered by AGN-like continuum sources [SDSS J092712+294344 at z= 0.713 (Komossa, Zhou and Lu 2008), SDSS J153636+044127 at z= 0.38 (Boroson and Lauer 2009) and SDSS J105041+345631 at z= 0.272 (Shields, et al. 2009b)] has opened up possibilities to study recoiling black holes and/or binary inspiralling supermassive black holes. **M. Vivek, R. Srianand, P. Noterdaeme, Vijay Mohan** and *Kuriakose* have studied the first object (i.e., SDSS J092712.64+294344.0, hereafter J0927+2943) in detail using facilities at IUCAA Girawali Observatory.

J0927+2943 is an unusual quasar with z= 0.713, identified by Komossa, et al. (2008) during their search for AGN with high [O III] velocity shifts. There are two systems of emission lines identified in the SDSS spectrum with a velocity separation of about 2650 km s^{-1}. One is referred as 'red' (with z_r= 0.71279) and other as 'blue' (with z_b= 0.69713). The red system consists of narrow emission lines (NELs) of [O III]λ5008, [O II]λ3727, [Ne III]λ3869, [Ne V]λ3426 and narrow Balmer lines. The blue system shows classical

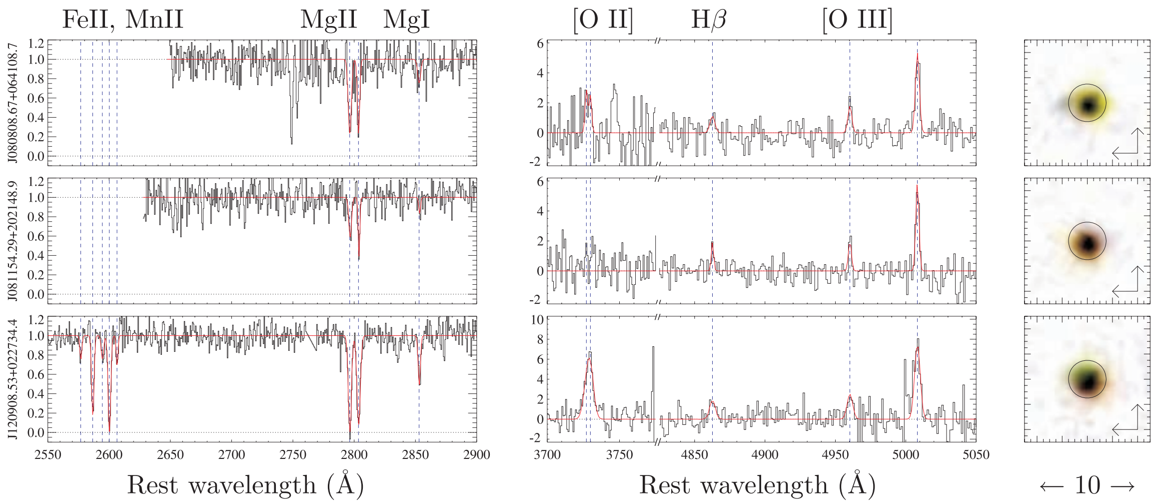


Figure 12: Absorption (left) and emission (middle) lines from the intervening galaxies. Note that in the left panels (absorption), the spectrum is normalised by dividing the observed spectrum by the QSO continuum, while in the middle panels (emission), the QSO continuum is subtracted from the observed spectrum and the flux-scale is in units of 10^{-17} erg s^{-1} Å^{-1}. Best fitted absorption and emission lines are overplotted. The SDSS images of the QSOs are shown in the right panels. The black circle represents the position of the 3-diameter SDSS fibre. North is top and East is left.

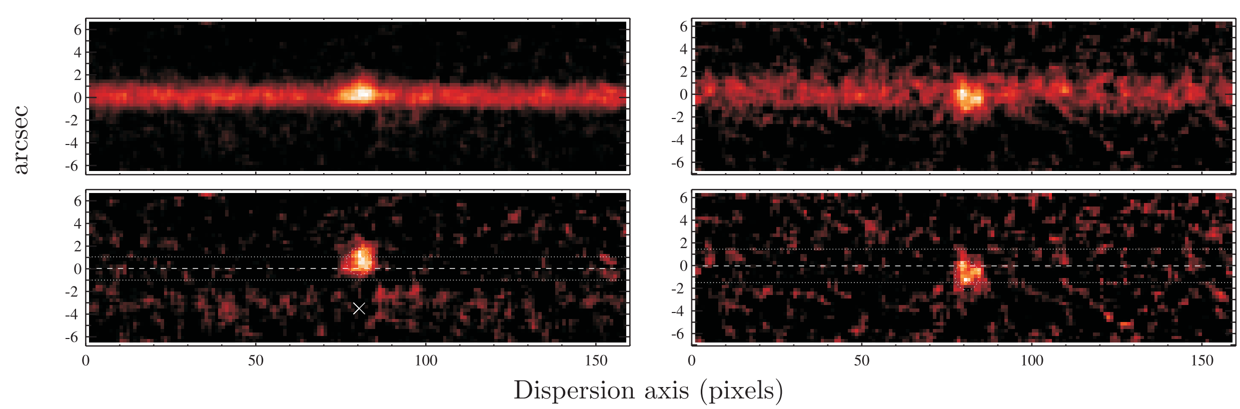


Figure 13: The background-subtracted 2D spectra of the quasar SDSS J113108+202151 and the galaxy at $z_{gal} = 0.56$. Top: Total (quasar+galaxy) spectra obtained with two slit orientations (left: P1, 10 degrees from North; right: P2, 92 degrees from North). Bottom: Same spectra after removing the quasar trace. The centre of the quasar trace is represented by the horizontal dashed lines, and its FWHM by the horizontal dotted lines. The ellipses represent the FWHM of a 2D-Gaussian fitted over the galaxy emission line. The 'X' on the bottom left panel represent the expected position of a [O II] emission line located 3.5 south from the quasar, i.e., at the centroid of the galaxy resolved by the SDSS. The data has been smoothed 2×2 pixels.

Balmer and Mg II broad emission lines, plus unusually broad NELs. The line ratios indicate AGN-like excitation in both systems. Shields, Bonning and Salviander (2009a) re-observed this object with the Hobby Eberly Telescope and reported a third redshifted set of narrow lines at $z \sim 0.7020$. They also put a bound on the line-of-sight acceleration between the red and blue systems (i.e., a 3σ limit of $dv/dt \leq 24$ km s^{-1} yr^{-1}).

Simulations of binary black hole mergers predict large recoil velocities (kicks) of the final merged black hole resulting from anisotropic emission of gravitational radiation. In the discovery paper, Komossa, et al. proposed J0927+2943 as a possible candidate for a supermassive black hole (with M$\sim 10^{8.8}$ M$_{\odot}$) ejected at high speed from the host galactic nucleus by gravitational radiation recoil. However, Dotti and Volonteri (2009) have proposed an alternate hypothesis in which, the observed configuration of emission lines originate from binary black holes. The main features of this model are the prediction of a detectable acceleration over a time-scale of years and subparsec scale sizes for the emitting regions. At the same time, Heckman, et al. (2009) proposed that J0927+2943 could be a high-redshift analogue of NGC 1275 (also known as 3C 84 and Perseus A), where two sets of redshifted emission lines are seen due to the interactions between two galaxies in a cluster centre (Conselice, et al. 2001). On similar lines, Shields, et al. (2009a) have proposed the superposition hypothesis based on the third redshifted emission line component and a possible presence of substantial cluster apparently containing J0927+2943. Subsequent detailed multiband photometric studies do not substantiate the presence of a massive cluster at the redshift of J0927+2943 (see Decarli, Reynolds and Dotti 2009). However, it is still possible that J0927+2943 is part of a massive cluster with low luminous matter to dark matter mass ratio. The absence of observable change in the redshifts of the emission lines and/or a clear proof of the line emitting gas spread over kiloparsec scales will clearly challenge the binary black hole scenario and favour the other two alternatives.

Vivek, et al., have reported a detailed analysis of long-slit spectroscopic observations of J0927+2943 taken at IGO. Comparing their extracted one-dimensional spectrum with the SDSS spectrum, obtained 4 years before, they place a 3σ constraint on the acceleration between the red and blue component to be less than 32 km s^{-1} yr^{-1} (see Figure 14). This is a factor of 3 smaller than the one expected for the binary black hole model (Bogdanovi, et al. 2009). However, this alone could not rule out the binary black hole model but rather tightens the constraints on the orbital parameters (see Shields, et al. 2009a). Moreover, one of the directly testable predictions of this model is the compact sizes (sub-parsec scale) of the emitting regions (Dotti and Volonteri 2009). The 2-D spectral analysis of **Vivek**, et al shows that the [O III] emission from the red component originates from an extended region of size $\sim$8 kpc (See Figure 15). This observation probably rules out the binary black hole model for J0927+2944.

In the frame work of recoil model with maximally spinning holes, one expects the maximum possible kick of $\sim$4000 km s^{-1} (Campanelli, et al. 2007a). The extended emission from the red component can be understood in this model as an effect of photoionization by the accretion disc emission associated with the recoiling black hole. Off-centred emissions are also expected in these models (see Haehnelt, Davies and Rees 2006; Loeb 2007; and Guedes, et al. 2009). Thus, extended [O III] emission from the red component or the slight offset they found for this emission with respect to the QSO trace alone cannot rule out the recoiling black hole scenario.

Heckman, et al. (2009) have proposed that J0927+2943 could be a high-redshift analogue of NGC 1275. Based on a simple model of infalling gas photoionized by the QSO continuum, Heckman, et al. suggested that the observed emission lines could be produced by a gas of density 300 cm^{-3} at a distance of 8 kpc from the QSO with a projected area of 12 kpc^2. The extent of the gas they have found ($\sim$ 8 kpc) for the red component is consistent with Heckman, et al.'s simple picture. However, it is important to note that in the case of NGC 1275 21 cm and X-ray absorption is seen at the higher redshift suggesting the infalling gas is in between the observer and the continuum source (De Young, Roberts and Saslaw 1973). In their calculation, Heckman, et al. consider N(H) that will be optically thick to Lyman continuum radiation. Such gas is also expected to produce Mg II absorption if the infalling gas is well aligned with the QSO. In the SDSS spectrum, **Vivek**, et al., do not detect any Mg II absorption. However, detailed photoionization modelling is needed to rule out the in falling gas model based on the absence of Mg II absorption.

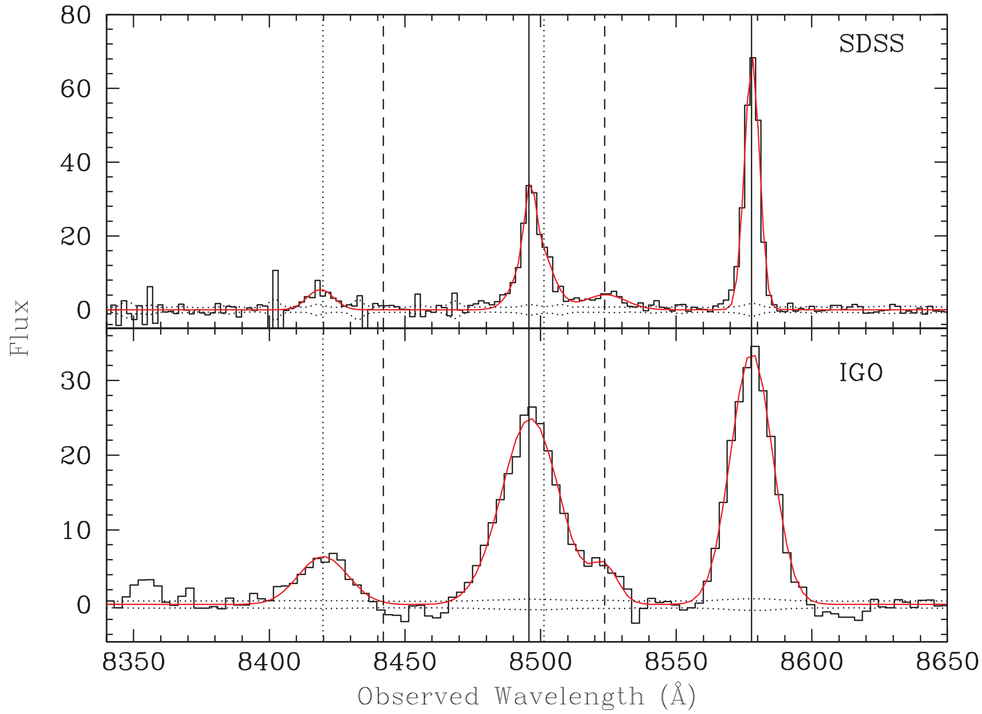


Figure 14: Comparison of the spectra of SDSS J0927+2943 obtained with IGO and SDSS. Best fit Gaussians are over-plotted. The solid, dotted and dashed vertical lines mark the locations of the different [O III] lines from the red, blue and the third system (at $z_{\rm em} = 0.7020$).

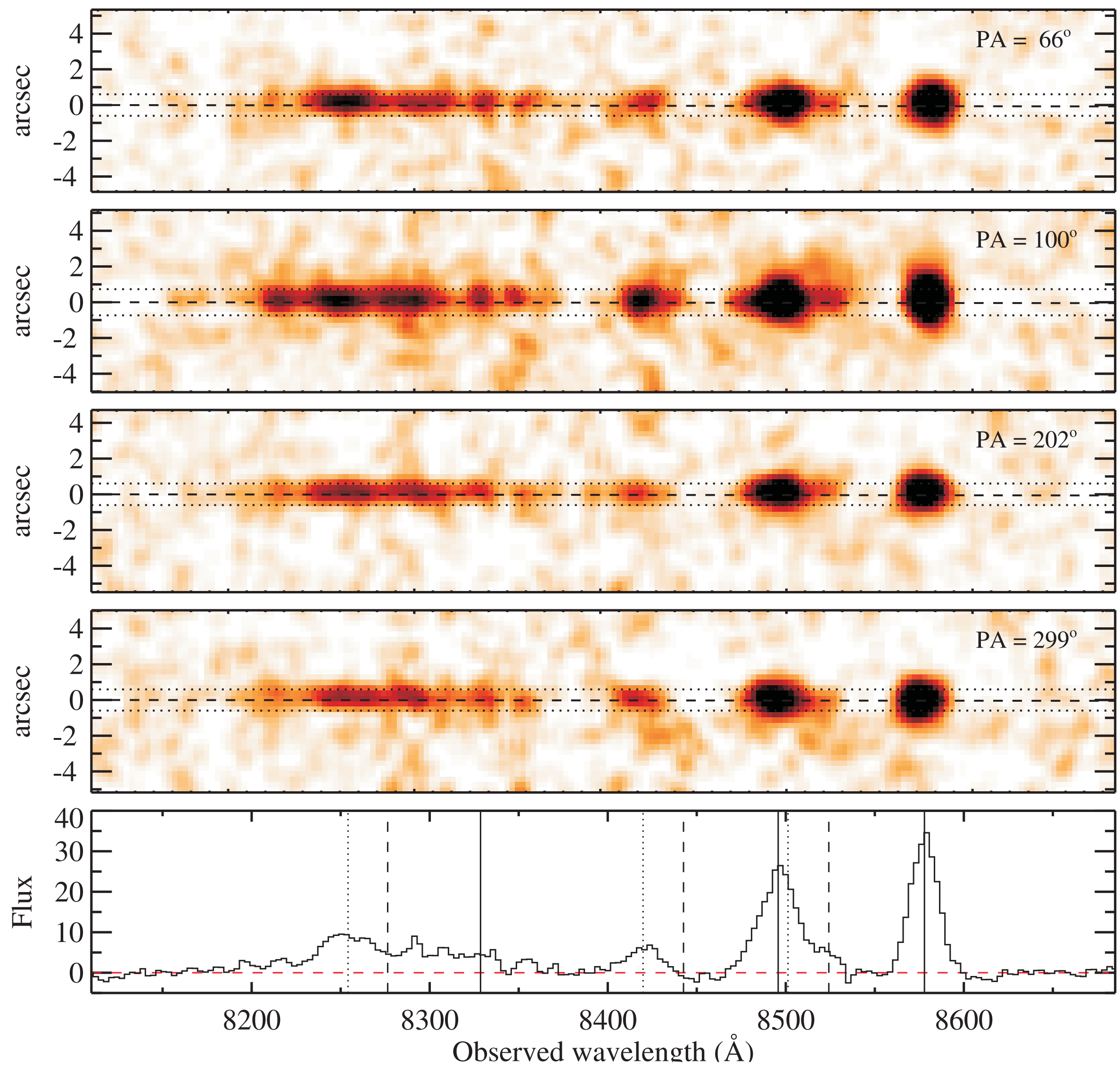


Figure 15: The 2D spectra of J0927+2943, in the Hβ and O III region, after subtraction of the QSO continuum are shown in the top four panels. The dashed line shows the centre of the trace used to remove the QSO continuum emission. The dotted lines mark the FWHM of the trace. The position angle (PA) of the slit is also given in each panel. The bottom panel gives the extracted 1D spectrum to enable identifications of different features in the 2D spectra. The vertical lines are as in Figure 14.

Vivek, et al.'s observations confirm the [O III]λ5008 from z_{em}= 0.7028 reported by Shields, et al. (2009a). To explain the three redshifted emission lines, Shields, et al. (2009a) proposed a hypothesis in which different emission components originate from a chance alignment of galaxies that are part of a massive cluster. However, there is no clear indication of J0927+2943 residing in the centre of a galaxy cluster (see Decarli, et al. 2009). In the recoil models, this third emission line component has to come from the unbound gas that got kicked also with the black hole. Future deep observations under better seeing conditions are needed to provide a strong constraint on the spatial extent of the third system.

Evolution of the cosmological mass density of neutral gas from Sloan Digital Sky Survey II - Data Release 7

Determining the cosmological mass density of neutral gas ($\Omega_{\rm HI}$) and its evolution in time is a fundamental step forward towards understanding how galaxies evolve. In the local universe, neutral gas is best traced by the hyperfine 21-cm emission of atomic hydrogen. Its observation allows for an accurate measurement of the neutral gas spatial distribution in nearby galaxies and strongly constrains the column density frequency distribution (Zwaan, et al. 2005). However, the limited sensitivity of current radio telescopes prevents direct detections of H I emission beyond $z \sim 0.2$.

At high redshift, most of the neutral hydrogen is revealed by the damped Lyman-α (DLA) absorption systems detected in the spectra of background quasars. Since DLAs are easy to detect and the H I column densities can be measured accurately, it is possible to measure the cosmological mass density of neutral gas at different redshifts, independently of the exact nature of the absorbers, provided a sufficiently large number of background quasars is observed. However, any bias affecting the selection of the quasars or the determination of the redshift path-length probed by each line of sight can affect the measurements.

Pasquier Noterdaeme and **R. Srianand**, with their collaborators (Patrick Petitjean and Cedric Ledoux) have recently demonstrated the feasibility and the robustness of a fully automatic search of SDSS-DR7 for DLA systems based on the identification of DLA profiles by correlation analysis. This led to the identification of about one thousand DLAs, representing the largest DLA database to date. They have tested the accuracy of the N(H I) measurements and quantified the high level of completeness and reliability of the detections.

In agreement with previous studies, they have shown that a single power-law is a poor description of the N(H I)-frequency distribution at log $N(H\ I) \geq 20.3$. A double power-law or a Γ function give better fits. The finding of one $\log N(H\ I) = 22$ DLA in SDSS data base, confirmed by UVES high spectral resolution observations, shows that the slope of the column density distribution at $\log N(HI) > 21.5$ is -3.5.

The convergence of Ω_{DLA} for large N(H I) indicates that the cosmological mass density of neutral gas at $z \sim 2.2 - 5$ is dominated by bonafide damped Lyman-α systems. The relative contribution of DLAs reaches its maximum around $\log N(H\ I) = 21$, similar to what is observed in the local universe. The paucity of very high-column density DLAs implies that they contribute for only a small fraction of the cosmological mass density of neutral gas. On the other hand, an extrapolation at $\log N(H\ I) < 20.3$ suggests that sub-DLA systems contribute to about one fifth of the neutral hydrogen at high redshift, in agreement with the results of Peroux, et al. 2005.

The main improvement in this survey is due to the identification of an important observational bias due to an edge effect. Using simulations they have proposed a method to avoid it. Such a bias could also partly explain the higher values of Ω_{DLA} found by Prochaska, et al. (2005) when selecting only bright quasars, as this bias preferentially affects faint quasars with lower signal-to-noise ratios. Indeed, when not correcting for the bias, they have found 10% higher Ω_{DLA} from a bright QSO subsample ($i < 19.5$), compared to a faint QSO subsample ($i \geq 19.5$) while this difference is only 5% when the bias is avoided.

They have also derived the evolution with time of the cosmological mass density of neutral gas in Figure 16. A decrease with time of the cosmological mass density of neutral gas between $z \sim 3.2$ and $z \sim 2.2$ is clearly seen in this figure. This confirms the results of Prochaska, et al. 2005 based on SDSS-DR5 data. However, **Noterdaeme**, et al. argue that the value at $z \sim 2.2$ is significantly higher (by up to a factor of two) than the value at $z = 0$, indicating that Ω_{DLA} keeps evolving at $z < 2.2$. Interestingly, models of the evolution of the reservoir of neutral gas also predict

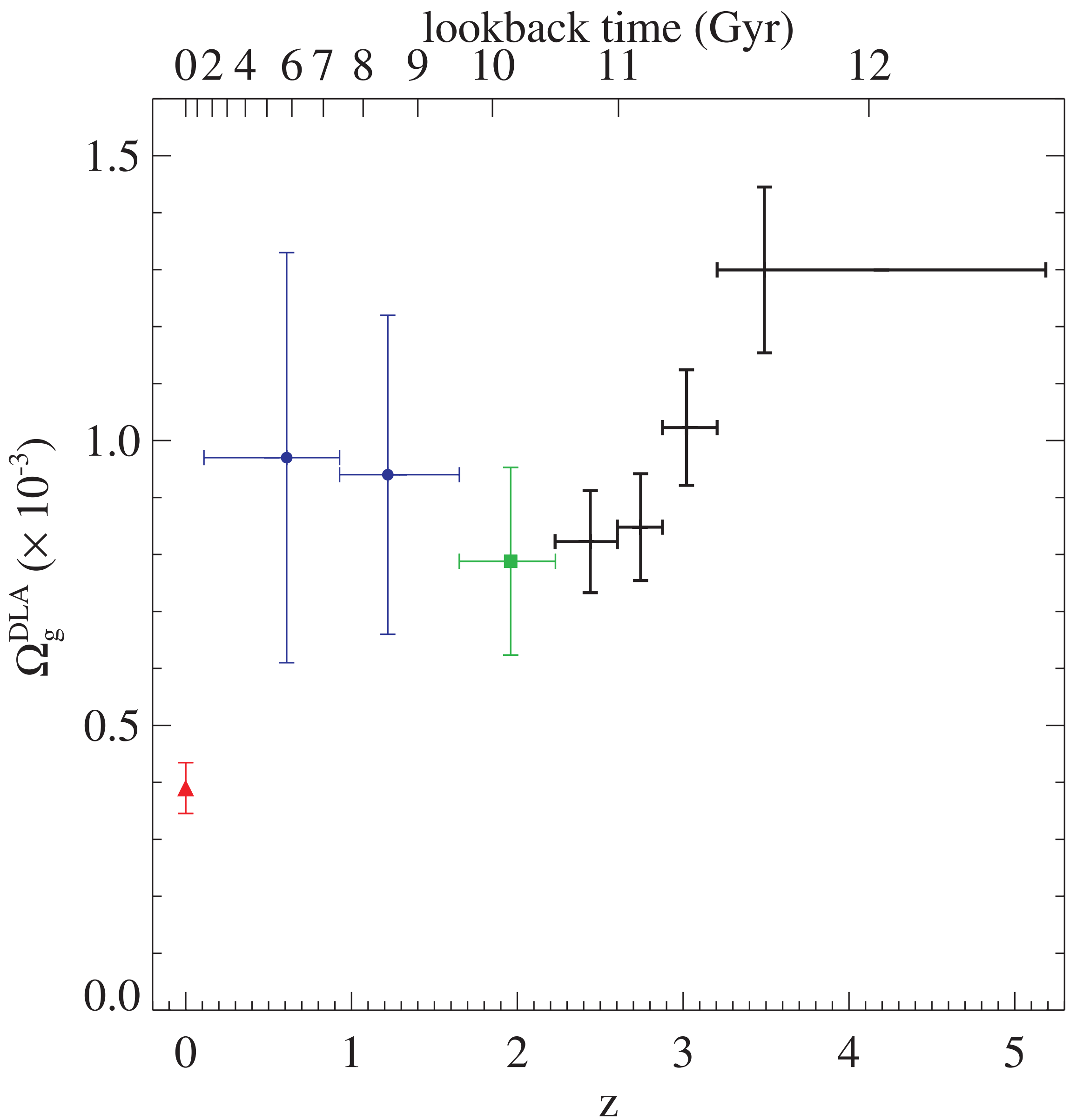


Figure 16: Cosmological mass density of neutral gas in DLAs, Ω_{DLA}, as a function of redshift. The red triangle at $z = 0$ is the value from 21 cm maps by Zwaan, et al. 2005. The blue filled circles at $z \sim 1$ are the measurements of Ω_{DLA} from Rao, et al. 2003. The green square at $z \sim 2$ is derived from the sample of Peroux, et al. 2003. Measurements at $z > 2.2$ are from the present work base on SDSS DR7.

a value of Ω_{DLA} at $z \sim 2.2$ higher than that at $z = 0$. The measured Ω_{DLA} at $z \sim 3$ is $\approx 10^{-3}$. This implies that neutral gas accounts for only 2% of the baryons at high redshift, according to the latest cosmological parameters from WMAP (Komatsu, et al. 2009) and most of the baryons are in the form of ionised gas in the intergalactic medium. The largest DLA sample built in this study is now made available to the scientific community at (http://cdsarc.u-strasbg.fr/cgi-bin/qcat?J/A+A/505/1087).

Detection of CO molecules and the 2175 Å dust feature at z = 1.64

Pasquier Noterdaeme, R. Srianand and their collaborators (Cedric Ledoux, Patrick Petitjean and Sabastian Lopez) have presented the detection of carbon monoxide molecules (CO) at z = 1.6408 towards the quasar SDSS J160457.50+220300.5 using the Very Large Telescope Ultraviolet and Visual Echelle Spectrograph. In their spectra, CO absorption is detected in at least two components in the first six A-X bands and one d-X(5-0) interband system. This is the second detection of its kind along a quasar line of sight. The CO absorption profiles are well modelled by assuming rotational excitation of CO in the range $6 < T_{\rm ex} < 16$ K, which is consistent with or higher than the temperature of the cosmic microwave background radiation at this redshift. They have derived a total CO column density of $N(CO) = 4 \times 10^{14} cm^{-2}$. The measured column densities of S I, Mg I, Zn II, Fe II, and Si II indicate a dust depletion pattern typical of cold gas in the galactic disc. The background quasar spectrum is significantly reddened (u-K $\sim$ 4.5 mag) and exhibits a pronounced 2175 Å dust absorption feature at the redshift of the CO absorber. Using a control sample of $\sim$ 500 quasars, they have found that the chance probability that this feature is spurious in $\sim$ 0.3%. They have shown that the spectral energy distribution (SED) of the quasar is well fitted by a QSO composite spectrum reddened with a Large Magellanic Cloud supershell extinction law at the redshift of the absorber. It is noticeable that this quasar is absent from the colour-selected SDSS quasar sample. This demonstrates that the current view of the universe may be biased against dusty sightlines. These direct observations of carbonaceous molecules and dust open up the possibility of studying the physical conditions and chemistry of diffuse molecular gas in high redshift galaxies.

Galaxy morphology and sizes at high redshifts

Massive galaxies that are very compact, and clumpy star-forming galaxies with masses $> 10^9$ $M_\odot$, that are found in the deep surveys carried out using the Advanced Camera for Surveys (ACS) on the Hubble Space Telescope (*HST*), are a unique population at high redshifts, $z > 1.5$. The measurements based on the ACS images for the $z > 1.5$ galaxies, reveal the rest-frame UV properties at these redshifts. However, with the installation of the Wide Field Camera 3 (WFC3), there is now access to the near-infrared images of comparable depth and spatial resolution, which probe the rest-frame optical properties of high-z galaxies. **Swara Ravindranath** and collaborators are investigating the evolution of galaxy morphology and sizes at $0.5 < z < 3$, using the early release data over the Hubble ultra deep field. They have found that at $z \sim 1.5$, the morphology and sizes measured for the early-type and late-type star-forming galaxies are comparable, while the intermediate-types show significant differences (Figures 17, 18). In collaboration with Harry Ferguson (STScI) and Huang Kuang-han (JHU), **Ravindranath** has been continuing to study the bi-variate luminosity-size function of Lyman-break galaxies at $z = 3$ and $z = 4$. Extensive Monte-Carlo simulations are being performed using the known functional forms for the luminosity and size distribution of galaxies, and quantify the measurement errors and biases.

A radio and x-ray view of cluster formation at the crossroads of filaments: ZwCl 2341.1+0000 at z = 0.28

As reported in previous annual reports, **Joydeep Bagchi** and his collaborators have discovered that diffuse synchrotron radio emission is detectable with an unusual system of large-scale filaments of galaxies extending over several Mpc. The galaxies clearly form a massive 'cosmic web' like structure found around the rich cluster ZwCl 2341.1+0000 at redshift z = 0.28. They have also found a corresponding extended x-ray source in the *ROSAT* PSPC all-sky survey, even though their flux estimate was based on a few x-ray photons in the short exposure of the survey. This study concluded that observations imply the existence of weak magnetic fields of strength $B \sim 0.3\,\mu$G, and, for the first time, direct evidence for the acceler-

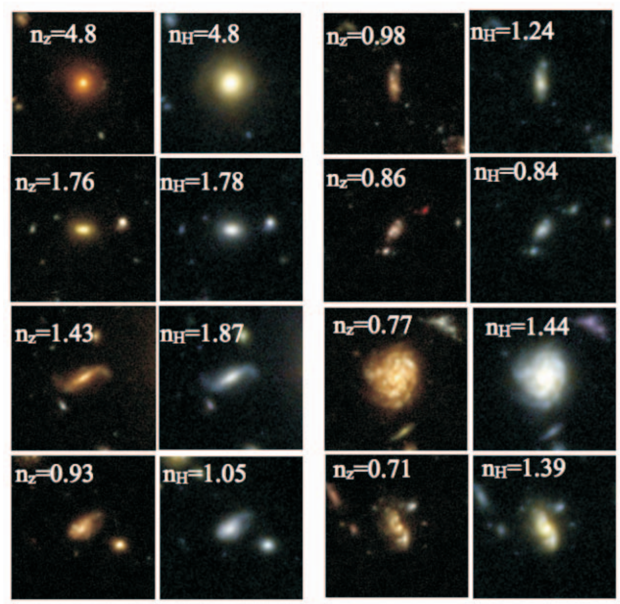


Figure 17: Comparison of the restframe UV and optical morphologies of galaxies at $z \sim 1.2$ in the Hubble Ultra Deep Field (HUDF). The left panel is a *viz* composite, and the right panel is the zJH composite. The Sersic Index, n, in the observed z-band (restframe UV) and H-band (restframe optical) are shown.

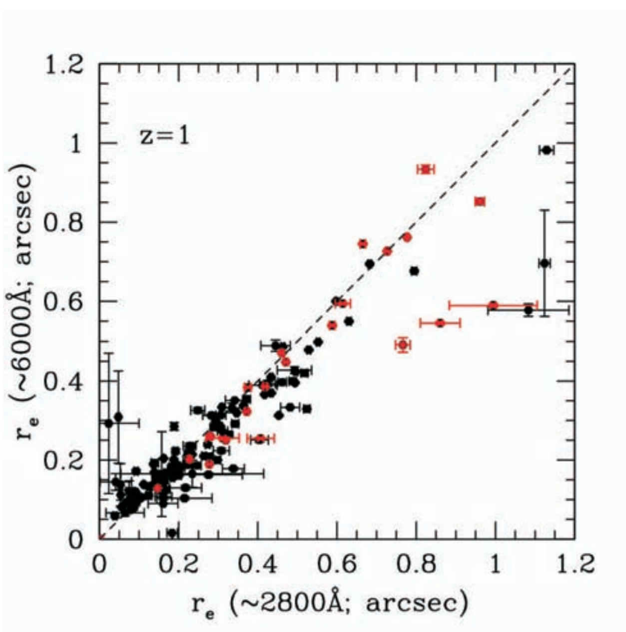


Figure 18: Half-light radii for galaxies at $z \sim 1.2$ selected from the HUDF. The black points are galaxies for which the photometric redshifts are used, and red points are those with available spectroscopic redshifts.

ation of relativistic electrons at GeV energies extending over scales of $\gtrsim 3$ Mpc. **Bagchi,** et al. have suggested that ZwCl 2341.1+0000 is a large-scale proto-cluster of galaxies in the process of its formation, where supersonic accretion of intergalactic matter on to the central filamentary structure leads to wide-spread shocks, acceleration of cosmic ray particles and amplification of weak magnetic fields. A recent high sensitivity VLA 1.4 GHz radio observation at $\sim 80''$ resolution has revealed diffuse, coherent polarized radio emission all along the central optical filament of galaxies. This corroborates the original finding that diffuse radio emission and magnetic field is distributed on a vast scale across this Mpc-scale filament of galaxies.

Bagchi and collaborators have made substantial efforts for better understanding the complex astrophysics of this unique structure using radio (GMRT) and x-ray (*Chandra* and *XMM-Newton*) observations. ZwCl 2341.1+0000 was jointly observed with *Chandra* for $\sim$ 30 ks and with *XMM-Newton* for $\sim$ 50 ks. The analysis of this extensive x-ray data has revealed some interesting new results. Along with the thermal x-ray observation, this striking filamentary structure of galaxies was also mapped with GMRT at the frequencies of 150, 240 and 610 MHz for probing the possible non-thermal components (magnetic field and cosmic ray particles). The first scientific results from the joint analysis of x-ray and radio data and their interpretation have been obtained, and have been reported. Furthermore, on theoretical front, they have also carried out a large-scale numerical simulation of structure formation shocks and turbulence for understanding the role they may play in such proto-clusters (these simulation results are presented elsewhere).

Hierarchical models of large-scale structure (LSS) formation predict that galaxy clusters grow via gravitational infall and mergers of smaller subclusters and galaxy groups. In this model, galaxy clusters form and evolve by progressive merger of smaller virialized halos, preferentially at the junction of filaments. Sometimes, diffuse radio emission, in the form of radio halos and relics, is found in clusters undergoing a merger, indicating that shocks and plasma turbulence associated with the merger are capable of accelerating electrons to highly relativistic energies. During a merger event, a significant amount of gravitational energy is released; of the order $10^{63}-10^{64}$ erg for the most massive mergers according to these models. All massive clusters must have undergone several mergers in their history and presently many clusters are still in the process of accreting matter. Key properties for testing models of large-scale structure formation include the total energy budget and the detailed temperature distribution within a cluster, which are both strongly affected by the cluster's merger history. Moreover, the physics of shock waves in the tenuous intra-cluster medium (ICM) and the effect of cosmic rays on galaxy clusters are all fundamental for our understanding of LSS formation. One of the interesting open questions in cosmic structure formation is: how much shock heating and cosmic ray acceleration can happen in the caustic shocks (near the accretion radius) in the formation of large-scale structures? While these questions have been addressed by simulations, the physics is still too complex to be easily predictable *ab initio*. Therefore, it is only through observations that one will learn how important these effects are. The observation of large scale radio synchrotron features of cosmic ray electrons in the extended filamentary structure of ZwCl 2341.1+0000 seems to be a very important clue to gain insight into this question. It serves as a natural laboratory for understanding the processes mentioned above.

In the hierarchical growth of structures, it is well-known that clusters accrete galaxies and intergalactic gas from intercluster filaments feeding clusters, This infalling gas can be accelerated and shock-heated. The effect of such infall is seen in the stellar population of galaxies, as well as galaxy-galaxy interactions among those falling in along filament cause bursts of star formation activity. ZwCl 2341.1+0000, clearly a remarkable system, appears to be an unusually massive and complex proto-cluster of galaxies, which is presently under assembly at the crossroad of several filaments. As the canonical cluster building activity proceeds hierarchically via infall and merger of sub-halos, the initially cold gas bound to these systems (mainly groups and clusters) should soon heat up by shocks and compression and be visible in x-rays. This is clearly revealed in our x-ray data. The Figure 19 shows a smoothed and combined (EPIC MOS and PN) image of the thermal x-ray emission in the energy range 0.5–3 keV observed with *XMM-Newton*. Here many clumps of intense X-ray emission associated with the infalling or merging galaxy clusters and groups are visible. These systems are seen embedded within the diffuse x-ray emission of much lower surface brightness. Thus, x-ray observations

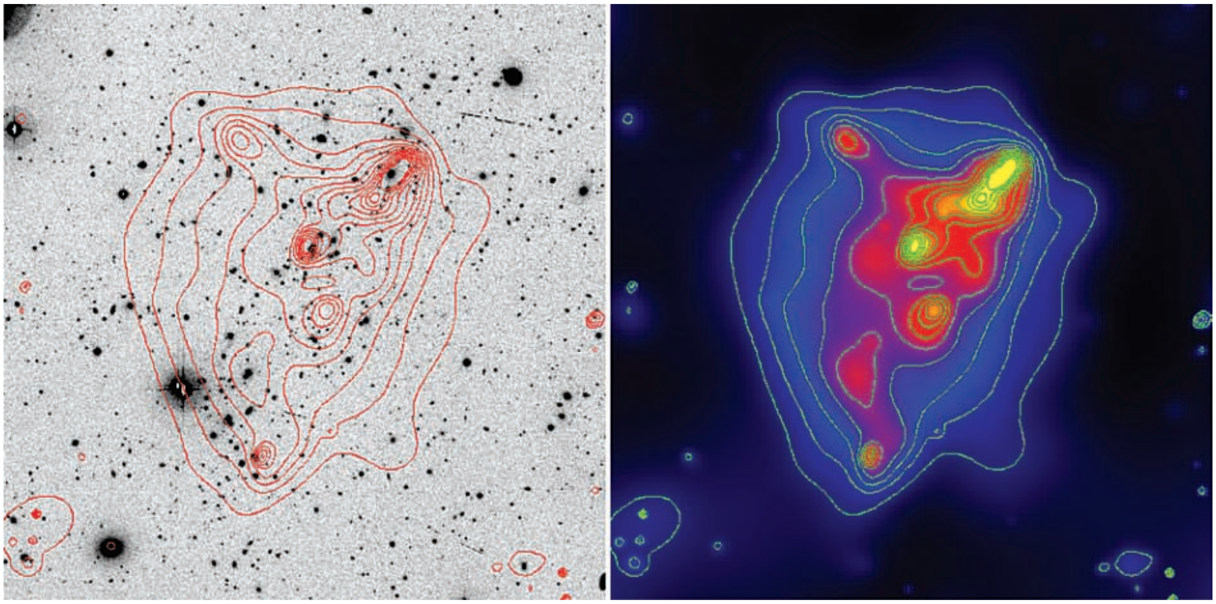


Figure 19: Left panel: Large-scale galaxy distribution around ZwCl 2341.1+0000. The optical R band image is shown – a combination of several individual exposures resulting in a total exposure time of 7800 s – was obtained with the WFI at the MPG/ESO 2.2 m telescope. Contours show the X-ray emission intesnsity observed by *XMM-Newton*. The image shows an area of $16' \times 16'$ (~ 4 Mpc $\times$ 4 Mpc) in size. Right panel: The smoothed and combined (EPIC MOS and PN telescopes) image of the thermal X-ray emission from ZwCl 2341.1+0000 in the energy range $0.5 - 3.0$ keV observed with *XMM-Newton*. Point sources have been removed from the main cluster region. There are several prominent groups or clusters visible in a complex merger ensemble. These are seen embedded within diffuse x-ray emission of much lower surface brightness.

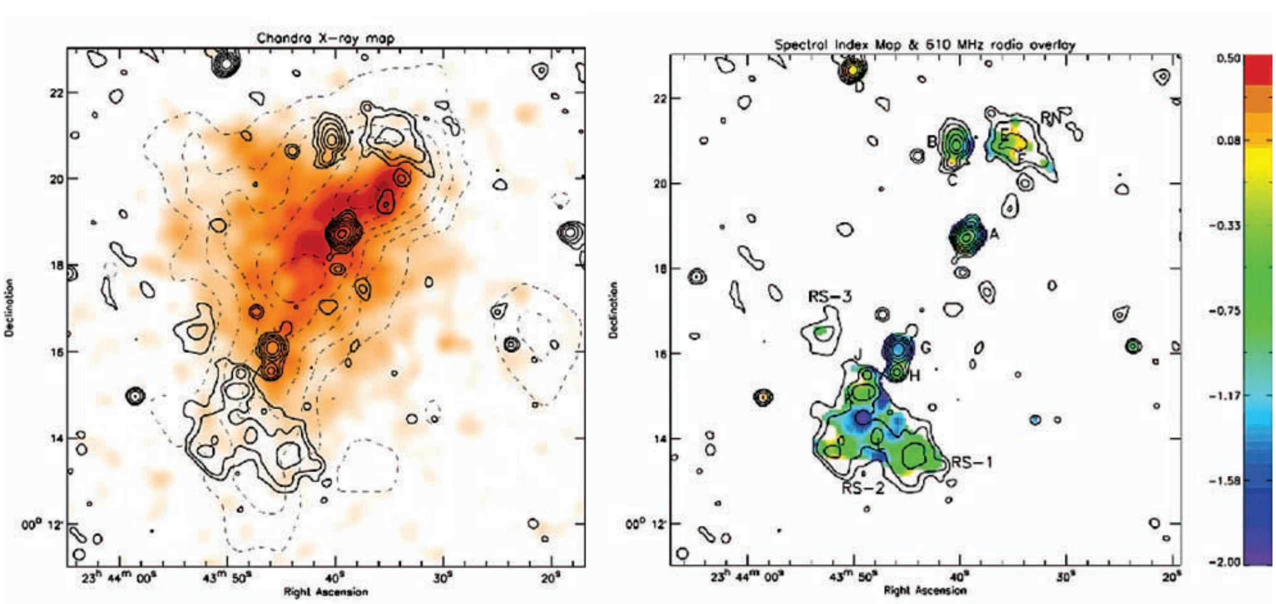


Figure 20: Left panel: Image of x-ray emission from ZwCl 2341.1+0000 observed by *Chandra* in the 0.5 - 3.0 keV energy band. Point sources were excluded from the image. The solid contours represent the radio emission at 610 MHz from the GMRT. The radio map has been convolved to a circular beam of 15 arcsec to better show the diffuse radio emission. The radio contours are drawn at $[1, 2, 4, 8, 16, 32, ...] \times 0.224$ mJy/beam. Dashed contours show the galaxy isodensity contours from SDSS, corresponding roughly to a limit of $M_V = -18.1$ (i.e., $M^* + 2.4$). The dashed contours are drawn at [2, 3, 4, 5,...] galaxies arcmin^{-2}. In addition to the peripheral radio emission, classified as a double relic, diffuse emission is detected along the optical filament of galaxies (not shown here). Right panel: Spectral index map between 610 and 241 MHz with a resolution of 18 arcsec. The black contours show the 610 MHz radio map. The radio contours are drawn at the same levels as on left.

clearly reveal ZwCl 2341.1+0000 to be one of most complex merging structures known so far.

The temperature map obtained from *Chandra* and *XMM-Newton*, both show extremely non-isothermal, filamentary structure of ICM having gas temperatures, which ranges between 2 and 9 keV (Figure 21). In addition, the x-ray morphology is obviously very disturbed and very far from a simple structure expected in a relaxed cluster. This is fully consistent with the notable filamentary branching structure of optical galaxies, apparently forming a Mpc-scale 'cosmic-web', suggesting a very massive galaxy cluster under collapse, and presently caught in a evolutionary phase far from virialization. Several 'cold-front' like features can be clearly discerned in temperature map which may indicate ingress of cold gas along the filaments and several other smaller blobs of cold matter falling into the main cluster, thereby, again suggestive of ongoing build up of a large scale structure. Interestingly, the GMRT radio map of the structure at 610 MHz (Figure 20) clearly detects two extended regions of diffuse emissions located to the north and south peripheral ends of the large galaxy filament. The separation between the two sources is about 10 arcmin or $\sim$ 2.5 Mpc. As these sources are truly diffuse and do not appear to originate from compact AGN sources, they were interpreted as being the elusive 'radio relics' originating in high energy particles accelerated in structure formation shocks. The presence of magnetic fields in the cluster on scales $\sim$1 Mpc and above is demonstrated from the observed synchrotron radiation, and the magnetic field strength can be estimated by assuming minimum energy densities in the radio sources. The radio spectral indices for the relic sources found are relatively flat, -0.49 ± 0.18 for the northern relic and -0.76 ± 0.17 for the southern relic.

Bagchi, et al. have derived an equipartition magnetic field of $B_{\rm eq} = 0.59\ \mu$G for the northern relic (assuming k = 1, ν_{low} = 10 MHz, ν_{hi} = 10 GHz), and $B_{\rm eq} = 0.55\ \mu$G for the southern relic. They have interpreted the diffuse radio emission observed in the periphery of ZwCl 2341.1+0000 as a double radio relic, possibly arising from acceleration of cosmic ray particles in shocks of cluster formation. This interpretation is based on (i) the location of the diffuse radio emission with respect to the x-ray emission; (ii) the presence of an elongated structure of galaxies in optical images; (iii) the orientation of the symmetry axis of the double relic being perpendicular to the elongation axis of the x-ray and optical emission; (iv) the morphology of the x-ray emission; (v) the lack of a direct connection between the diffuse emission and the radio galaxies within the cluster; and (vi) the presence of 'head-tail' galaxies, which are commonly found in merging clusters. This is all quite clear evidence that one is witnessing a remarkably complex merging system of infalling subclusters, where electrons are (re-)accelerated by large-scale shocks. Neither the *Chandra* nor the *XMM-Newton* x-ray images show any shock fronts at the location of the radio relics. However, both observations are probably too short to see any sharp details in the low-brightness x-ray regions so far away from the cluster centre. Thus, their observations give a foretaste of how physics of structure formation can be understood better by combining deep optical, radio and x-ray observations. Far more sensitive and detailed observation of structure formation process in hundreds of clusters will be possible in near future with upcoming new generation radio telescopes like SKA, LOFAR and ALMA, and new x-ray observatories like NuSTAR, XEUS and SIMBOL-X, that will open a new window to the large-scale cosmos.

Active Galactic Nuclei, Quasars, and IGM

Analysis of AGN light curves

Temporal analysis of astrophysical sources like Active Galactic Nuclei, X-ray Binaries and Gamma-ray bursts provide information on the geometry and size of the emitting regions. Robustly establishing that two light-curves in different energy bands are correlated is an important temporal diagnostic and a necessary step before any further analysis (like measuring time lags) can be undertaken. **Ranjeev Misra**, A. Bora and **Gulab C. Dewangan** have presented an analytical expression to estimate the error on the cross-correlation between two light-curves. Earlier estimates depended upon numerically expensive simulations or on dividing the light-curves in large number of segments to find the variance. Thus, the analytical estimate presented allows for analysis of light-curves with relatively small ($\sim$1000) number of points, as well as to obtain correlation on the longest time-scales available. The error estimation is verified using simulations of light-curves derived from both white and 1/f stochastic processes with measurement errors.

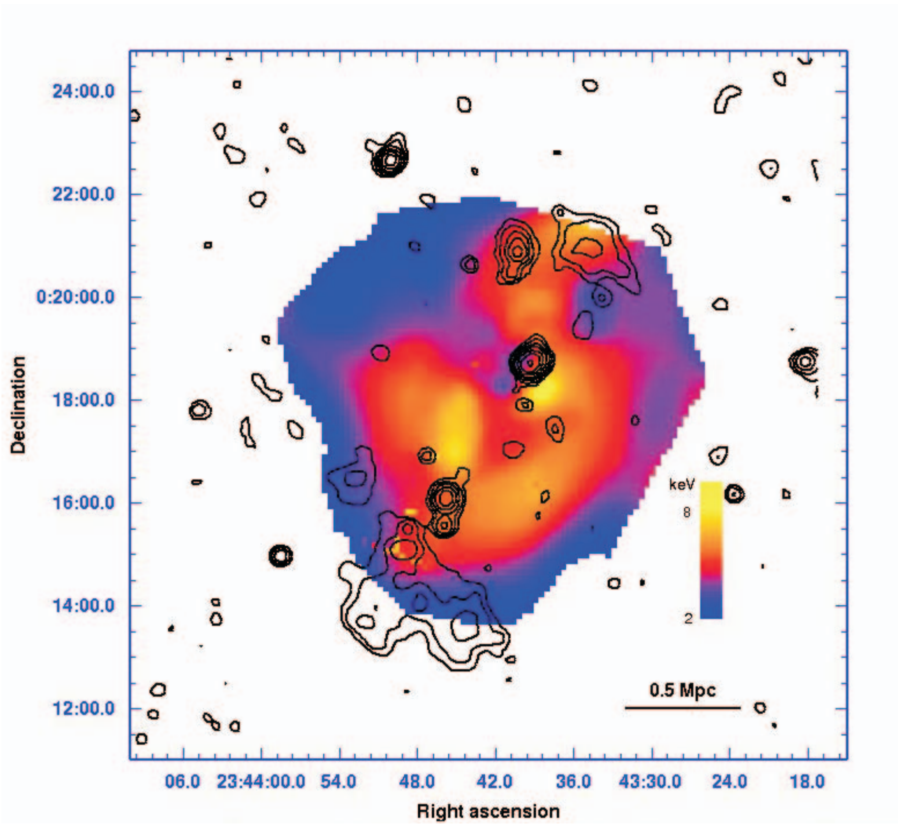


Figure 21: An x-ray temperature map of ZwCl 2341.1+0000 obtained by combining the *XMM-Newton* MOS-1&2 and *Chandra* ACIS-I observations. The colour bar shows the correspondence between temperature and the colours used. The contours show the 610 MHz radio emission map observed by GMRT shown in the previous figure.

As a demonstration, they apply this new technique to analyse light-curves of AGN.

Identifying binary black hole systems

The hierarchical models of galaxy formation and evolution imply that when two galaxies merge, dynamical friction would bring their central black holes closer, and they will form a massive black hole binary system. These massive binary black holes will eventually spiral in and merge to form a single central supermassive black hole of the new galaxy. While observations have revealed the presence of black holes separated by thousands of light years, evidence for close binary systems with separations less than the sizes of the optical broad-line regions (a few light days to several light years) is lacking. **Gulab C. Dewangan** and **Ranjeev Misra** have devised a new technique, which can unambiguously identify close binary systems, irrespective of their separation, using their broad band X-ray emission. If one of the sources is highly absorbed, the system will have unique X-ray spectrum and variability signatures, which can be distinguished from any other possible scenarios. **Dewangan** and **Misra** apply this technique to the Suzaku X-ray observations of several active galactic nuclei and identified the distant (z = 3.91), gravitationally lensed quasar APM 08279+5255 as a close binary system of supermassive black holes with 10 and 1 billion solar masses with a separation less than the size of their common broad-line region. Their findings support the results obtained from numerical simulations of galaxy mergers that suggest large scale high velocity outflows caused by merging supermassive black holes. With this new technique, the prospects of finding close binary system of massive black holes will have an important impact on our understanding of black hole growth and galaxy evolution.

The high resolution spectroscopy of the soft x-ray spectrum of the AGN Mrk704.

The 0.1-10 keV spectra of many quasars and other Active Galactic Nuclei (AGNs) have been found to be modified by the absorption features of partially ionised material along our line of sight and intrinsic to the source. Such x-ray absorbing clouds has been named the "ionised absorber" or the *"warm absorber"*. **Sibasish Laha, Gulab C. Dewangan and Ajit K. Kembhavi** have studied the soft x-ray spectrum of a nearby luminous AGN Mrk 704 ($z \sim 0.029$), which presented a significant warm absorption. The source was selected because of its unique property of being a Polar Scattered Seyfert (PSS) galaxy. Following the unification scheme, these AGNs are viewed with an inclination comparable with the "torus" opening angle, and hence, the line of sight to the nucleus passes through the upper layers of the torus. They have used the high resolution data from the Reflection Grating Spectrometer of the XMM-Newton satellite mission. The warm absorption features were extensively modelled using the photoionisation code CLOUDY. They have found two distinct warm absorbing outflows, having distinct ionisation states and column densities. The lower ionisation state ($\log(\xi)=1$) contributes to the Fe M-shell Unresolved Transition Array, while the higher ionisation state ($\log(\xi) = 2.65$) gives rise to the absorption from OVII, NVII, CVI, and NeIX. It was noted from the redshift that the higher ionisation phase has a lower outflow velocity ($v \sim 400$ km s^{-1}) while the lower ionisation phase has a higher outflow velocity ($v \sim 1500$ km s^{-1}) with respect to the systemic velocity. This is an indication that the wind is radiatively driven by the continuum flux. They have also detected weak emission features in the soft x-rays mainly coming from the He-like triplets of OVII and NVI. The emission lines when modelled with CLOUDY were found to have the same range of physical parameters as the warm absorption clouds. They have detected that one of the emission lines (*resonant*) in both the triplets is highly blueshifted compared to the other two lines (*intercombination* and *forbidden*) of the triplets. It indicates that the *resonant* line is emitted from a very high velocity outflowing cloud ($v \sim 5000$ km s^{-1}) located nearer to the central source, while the other two lines are emitted from clouds much farther away from the source.

Magnetic Fields in Astrophysics

Large-scale magnetic fields in stars and galaxies are thought to be generated and maintained by a mean-field turbulent dynamo. Through the past year a number of issues related to such mean-field dynamos were investigated.

A nonperturbative quasilinear approach to the shear dynamo problem

S. Sridhar and **K. Subramanian** have studied large–scale dynamo action due to turbulence in the presence of a linear shear flow. Their treatment is quasilinear and equivalent to the standard 'first order smoothing approximation'. However, it is non-perturbative in the shear strength. They have first derived an integro-differential equation for the evolution of the mean magnetic field, by systematic use of the shearing coordinate transformation and the Galilean invariance of the linear shear flow. They have showed that for non-helical turbulence, the time evolution of the cross-shear components of the mean field do not depend on any other components excepting themselves; this is valid for any Galilean invariant velocity field, independent of its dynamics. Hence, to all orders in the shear parameter, there is no shear current type effect for non-helical turbulence in a linear shear flow, in quasilinear theory in the limit of zero resistivity. They then have developed a systematic approximation of the integro-differential for the case when the mean magnetic field varies slowly compared to the turbulence correlation time. For non-helical turbulence, the resulting partial differential equations can again be solved by making a shearing coordinate transformation in Fourier space. The resulting solutions are in the form of shearing waves, labeled by the wavenumber in the sheared coordinates. These shearing waves can grow at early and intermediate times but are expected to decay in the long time limit.

A reconnecting flux rope dynamo

A. W. Baggaley, C. F. Barenghi, A. Shukurov and **K. Subramanian** have developed a new model of the fluctuation dynamo in which, the magnetic field is confined to thin flux ropes advected by a multi-scale model of turbulence. Magnetic dissipation occurs only via reconnection of the flux ropes. The model is particularly suitable for rarefied plasma, such as the solar corona or galactic halos. This model can be viewed as an implementation of the asymptotic limit of infinite magnetic Reynolds numbers, for a continuous magnetic field, where magnetic dissipation is strongly localized to small regions of strong field gradients. They have investigated the kinetic energy release into heat, mediated by the dynamo action, both in the model and by solving the induction equation with the same flow. They have found that a flux rope dynamo is an order of magnitude more efficient at converting mechanical energy into heat. The probability density of the magnetic energy release in reconnections has a power-law form with the slope -3, consistent with the solar corona heating by nanoflares.

A. W. Baggaley, A. Shukurov C. F. Barenghi and **K. Subramanian** also have presented a nonlinear extension of the above model. This shows that a plausible saturation mechanism of the fluctuation dynamo is the suppression of turbulent magnetic diffusivity, due to suppression of random stretching at the location of the flux ropes. They have confirmed that the probability distribution function of the magnetic line curvature has a power-law form suggested by Schekochihin, et al (2002). They argue, however, that this does not imply a persistent folded structure of magnetic field, at least in the nonlinear stage.

Primordial magnetic fields and the HI signal from the epoch of reionization

The implication of primordial magnetic-field-induced structure formation for the HI signal from the epoch of reionization was studied. Using semi-analytic models, Shiv Sethi and **K. Subramanian** have computed both the density and ionization inhomogeneities in this scenario. They have showed that: (a) The global HI signal can only be seen in emission, unlike in the standard LCDM models, (b) the density perturbations induced by primordial fields, leave distinctive signatures of the magnetic field Jeans' length on the HI two-point correlation function, (c) the length scale of ionization inhomogeneities is of order a megaparsec. They have found that the peak expected signal (two-point correlation function) is $\simeq 10^{-4}\,K^2$ in the range of scales 0.5–3.0 Mpc for magnetic field strength in the range 5×10^{-10}–$3\times10^{-9}\,G$. They also discussed the detectability of the HI signal. The angular resolution of the on-going and planned radio interferometers allows one to probe only the largest magnetic field strengths that we consider. They have the sensitivity to detect the magnetic field-induced features. They have showed that the future Square Kilometre Array has both the angular resolution and the sensitivity to detect the magnetic field-induced signal in the entire range of magnetic field values. They consider, in an integration time of one week.

Magnetic fields in the early universe

K. Subramanian has reviewed, in a pedagogical fashion, two aspects of magnetic fields in the early universe. He has first focused on how to formulate electrodynamics in curved space time, defining appropriate magnetic and electric fields and writing Maxwell equations in terms of these fields. He then considered the specialized case of magnetohydrodynamics in the expanding universe and emphasized the usefulness of tetrads in this context. He also reviewed the generation of magnetic fields during the inflationary era, deriving in detail the predicted magnetic and electric spectra for some models. The potential problems arising from back reaction effects and from the large variation of the coupling constants required for such field generation has been discussed.

High Energy Astrophysics

Gamma ray bursts

Optical follow-ups of several gamma ray burst afterglows were attempted by at the IUCAA Girawali Observatory promptly after the GRB trigger, leading to upper limits on their optical brightness at early times **(Dipankar Bhattacharya, A.N. Ramaprakash, Vijay Mohan, Kuntal Misra).** The dual-frequency radio follow-up of the afterglow of the gamma ray burst of March 29 2003 with the GMRT was continued and the final data analysis has been in progress.

Bhattacharya and his Ph.D. student **Sandeep Kumar** have undertaken the work of Monte-Carlo radiative transfer in the magnetosphere of accreting neutron stars, in order to build theoretical model of the cyclotron absorption line spectra seen from such objects. Calculations involving multiple resonances, covering hard x-ray bands up to 150 keV, are being undertaken for the first time in this study. This spectral range is ideally suited to the forthcoming Indian satellite mission ASTROSAT. The final aim is to model phase resolved x-ray spectra of accretion-powered pulsars, and thereby, carry out a tomography of the magnetic field distribution at the polar cap.

A survey for rotation-powered pulsars is being carried out at the 610 MHz radio band with the GMRT by **D. Bhattacharya, Bhaswati Bhattacharyya** and collaborators [Y. Gupta, D. Lorimer and M. Kramer]. Data collected in the pilot phase of this survey are now being analysed using the IUCAA High Performance Computing system. Several promising candidates have been identified, which require further follow-up.

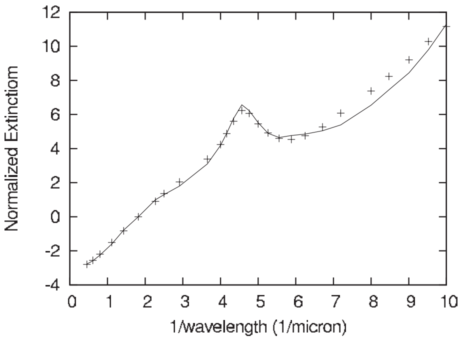


Figure 22: Interstellar extinction curve and the fit based on analytical formulation of the average observed extinction curve

Stars and Interstellar Medium

Frequency and size distribution of interstellar dust grains

In a recent paper, the frequency and size distribution dependence of extinction spectra for astronomical silicate and graphite grains was analyzed in the context of MRN type interstellar dust models in the far ultraviolet and ultraviolet regions. These grains were taken to be homogeneous spheres following a power law size distribution. Recently, Ashim Roy, Subodh K. Sharma and Ranjan Gupta have extended the analysis further to cover the visible, as well as the infrared part of the electromagnetic spectrum and Figure 22 shows a fit of our analytical formulation to the average observed extinction curve. The analytic formulas presented here along with those given in the earlier paper would enable one to evaluate extinction for these grains within a wider wavelength range 1,000Å - 22,500Å, and analyze the observational interstellar extinction data in far greater details.

Under the ongoing ISRO-RESPOND project entitled `Interpretation of the observed extinction in the optical-UV region from TAUVEX and ASTROSAT-UVIT satellite database', Nish Katyal, D.B. Vaidya and Ranjan Gupta have compared the composite grain model based extinction curves with various directions in our galaxy. Figure 23 shows a set of four such comparison fits

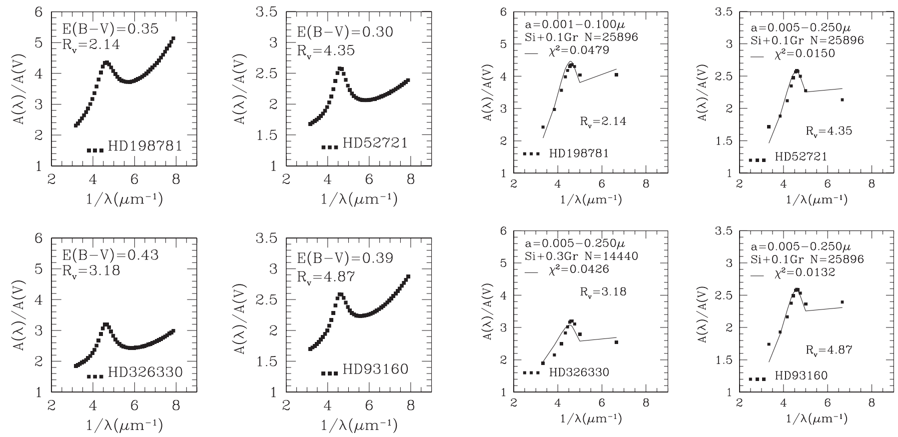


Figure 23: Interstellar extinction curves for typical selected directions in the galaxy (on left) and resultant composite dust grain model fits to these curves (on right)

in selected directions of the galaxy. The important conclusions are:

(i) Extinction efficiency of the composite grains increases with the increase of volume fraction of inclusions. The extinction feature at 2175Å seems to shift towards shorter wavelengths with the volume fraction of inclusions.

(ii) The composite grain models used in the present study seems to fit reasonably well with the extinction curves for $\sim$ 35 stars.

(iii) The 2175Å feature (width and strength) seems well correlated with the R_v.

(iv) In the regions with low R_v (= 2.14), smaller grains (a = 0.001-0.100μ) may be responsible for the extinction, whereas in the dense regions with higher R_v (range 3 - 5), larger grains (a = 0.005 - 0.250μ) may be responsible for the extinction.

Timing and spectral properties of x-ray binaries

X-ray binaries are stellar systems, where two stars are bound gravitaitonally and are orbiting about their common centre of mass. One of these stars is a compact object, either a neutron star (NS) or a black hole (BH). The other is a normal star usually also called a donor star as the compact object is accreting matter from this star. **Harsha Raichur**, et. al. have studied the timing and spectral properties of such system and some of the details of their work are summarized below.

1. It has long been argued that better timing precision allowed by sattelites like Rossi X-ray Timing Experiments (RXTE) will allow to measure the orbital eccentricity and the angle of periastron of some of the bright persistent high mass x-ray binaries (HMXBs), and hence, a possible measurement of apsidal motion in these system. Measuring the rate of apsidal motion allows one to estimate the apsidal motion constant of the mass losing companion star, and hence, allows for the direct testing of the stellar structure models for these giant stars present in the HMXBs. They have used the archival RXTE data of two bright persistent sources, namely Cen X-3 and SMC X-1, to measure the very small orbital eccentricity and the angle of periastron. They have found that the small variations in the pulse profiles of these sources rather than the intrinsic time resolution provided by RXTE, limit the accuracy with which we can measure arrival time of the pulses from these sources. This influences the accuracy with which one can measure the orbital parameters, especially the very small eccentricity and the angle of periastron in these sources.

2. Be/x-ray binary pulsars have wide eccentric orbits, and hence, the angle of periastron of the orbit is very well defined in these sources. The presence of an X-ray pulsar allows for accurate measurements of orbital elements. A Be-star usually is a rapidly rotating star, and hence, will deviate from spherical geometry. The tidal interaction between the neutron star and the Be-star will add to the

distortion of the Be-star and alter its mass distribution. Thus, a measurable rate of apsidal motion is expected from these systems. They have detected apsidal motion in the binary 4U0115+63 and they have also determined the orbital parameters of the Be/x-ray binaries V0332+53 and 2S1417-624.

3. Low mass x-ray binaries (LMXB) containing weakly magnetized neutron stars are further classified into Z and A - toll sources. Irrespective of the type of source, the radiative processes that produce the x-ray spectra in these sources are not well constrained. Phenomenologically, there are two approaches to model the spectra and it has not been able to distinguish between these two approaches primarily due to lack of good quality spectral data in the 0.1 - 2.0 keV range and the uncertainity in the absorption column density. In both the approaches, the spectrum is described as arising due to two main components, namely the disk component and the component due to the boundary layer between the disk and the neutron star surface. In one approach, the accretion disk is considered to be emitting a soft component while the boundary layer emits the hard Comptonised component. In the other approach, the boundary layer emits the cool black body component and the inner hot accretion disk emits the hard Comptonised component of the spectrum. **Harsha Raichur** has studied the broad band spectrum of the source Aql X-1 using the pointed RXTE and Suzaku observations of this source. This study will be extended to other known A-toll and Z-sources.

Investigation of the unique nulling properties of PSR B0818−41

Many pulsars are known to exhibit the phenomenon of nulling, where the emission appears to cease, or is greatly diminished, for a certain number of pulse periods. Though there has been significant progress both in the field of observations, as well as understanding and characterising the phenomenon of nulling, the reason behind pulsar nulling and its connection to the emission mechanism is not tightly pinned down. In this regard, study of the emission properties before and after nulls, for individual pulsars, assumes importance. **Bhaswati Bhattacharyya** and collaborator have studied the unique nulling properties of PSR B0818−41, using the GMRT at 325 and 610 MHz. This pulsar shows well defined nulls, with lengths ranging from a few tens to a few hundreds of pulses. They have estimated a nulling fraction of about 30% at 325 MHz. Furthermore, they have found the following interesting behaviour of the pulse intensities, pulse shapes, pulse widths and the drift rate, just before and after the nulls:

(i) There is a clear difference between the transitions from bursts to nulls and from the nulls to bursts. The pulsar's intensity does not switch off abruptly at the null, but fades gradually, taking $\sim 10P_1$. On the other hand, just after the nulls, the intensity rises to a maximum over a short (less than one period) time scale.

(ii) While the last active pulses before nulls are dimmer, the first few active pulses just after the nulls outshine the normal ones. This effect is very clear for the inner region of the pulsar profile, where the mean intensity of the last few active pulses just after the nulls is ~ 2.8 times more than that for the last active pulses just before the nulls.

(iii) There is a significant evolution of the shape of the pulsar's profile, around the nulls, especially at the beginning of the bursts: an enhanced bump of intensity in the inner region, a change in the ratio of the strengths of the leading and trailing peaks towards a more symmetric profile, an increase in profile width of about 10%, and a shift of the profile centre towards later longitudes. Some of these can be explained by a (temporary?) shift of the emission regions to different heights and/or slightly outer field lines in the magnetosphere.

(iv) Just before the onset of the nulls, for about 60% of the occasions, the apparent drift rate becomes slower (correlated with the gradual decrease of pulse intensity), transitioning to an almost phase stationary drift pattern. Further, when the pulsar comes out of the null, the increased intensity is very often accompanied by what looks like a disturbed drift rate behaviour, which settles down to the regular drift pattern as the pulsar intensity returns to normal. Thus, they have found some very specific and well correlated changes in the radio emission properties of PSR B0818−41 when the emission restarts after a null. These could imply that the phenomenon of nulling is associated with some kind of a "reset" of the pulsar radio emission engine.

Bhattacharyya has also found plausible explanations for some of the observed behaviour, using the Partially Screened Gap model of the inner pulsar accelerator.

Very old stars

A search for very old stars in the LMC has yielded plausible populations as old as 20 Gyr, as studied by their colour magnitude diagrams. These populations have been found in the archival records of the Hubble Space Telescope. A paper on this work by **Vijay Mohan**, Ferdinando Patat (ESO), **J.V. Narlikar** and Ken Freeman (ANU, Canberra) is under consideration for publication.

Instrumentation

Ultra Violet Imaging Telescope (UVIT)

UltraViolet Imaging Telescope (UVIT) is one of the 5 instruments to go on the first Indian astronomy satellite ASTROSAT; the other 4 instruments are x-ray telescopes. UVIT consists of two telescopes, each of aperture 380 mm. The two telescopes make images in a field of 28' with a resolution of $\leq$ 1.8", simultaneously in three channels: 1300 - 1800 A, 2000 - 3000 A, and 3200 - 5300 A. UVIT is being developed through a collaboration between several Indian institutions: IIA, ISRO, IUCAA, PRL, and TIFR, and Canadian Space Agency., **Shyam Tandon** has been coordinating this development as Programme Manager for the project.

This year, the flight models of the three detectors were completed by the Canadian Space Agency, and the flight mirrors were figured to 1/50 wavelengths at LEOS (ISRO). All the structural parts of the engineering model were also ready and assembly will start soon. It is expected that the engineering model would be fully tested for vibrations, etc. by May 2010. A successful completion of these tests would be followed by assembly and testing of the flight model. The Flight Model is due to be delivered to ISRO by September 2010 for integration with the satellite. Launch of the satellite is expected in early 2011.

FIFUI - Fibre-based Integral Field Unit for IFOSC:

An optical fibre based Integral Field Unit (IFU) for IUCAA 2m telescope has been developed in the instrumentation laboratory by **Mudit Srivastava**, and **A.N. Ramaprakash** along with the help of the Instrumentation team. It is implemented as one of the modes of IUCAA Faint Object Spectrometer and Camera (IFOSC), and would offer the facility to do area spectroscopy of extended astronomical objects. The IFU has been optimized for visible IFU-iras-spectra spectrum and consists of 100 fibres. The field of view of this IFU is about 13 arcsec x 6 arcsec with three modes of sky sampling, i.e., 1 arc-sec per fibre, 0.8 arcsec per fibre and 1.2 arcsec per fibre. The IFU consists of 3 optical sections as briefly described below.

Fore-Optics: The fore-optics of the IFU forms a magnified image of the sky on a lenslet array. It consists of three achromatic doublet lenses (one for each sampling scale) and a singlet lens. The singlet lens work as a field flattener, which sets the exit pupil of the fore-optics at infinity. A combination of one achromatic doublet with the singlet lens is used to provide one sampling scale. The achromatic doublets are mounted on a one-dimensional linear motorized translation stage (from Newport Corporation), so that any one of the three sampling scales can be achieved by moving the corresponding achromatic doublet in to the path of the light beam.

Lenslets and Fibre: The lenslet array is responsible for sampling of a 2-D field of view of the sky. The array has been fabricated from Plano-convex hexagonal shaped lenses (lenslets). 100 such lenslets are arranged in the form of a honeycomb structure to provide continuous spatial sampling of the sky image. Each lenslet produces a small pupil image on the fibre core, avoiding light loss due to inactive part of the fibres. Fibres having core diameter 70 microns are used to match the pupil image. Further, the lenslet array feed f/4 beam into the optical fibres, which is required to minimize the focal ratio degradation (FRD) effect.

The lenslets are of vertex to vertex diameter 2.1 mm and the convex surface has radius of curvature of 4.08 mm. For efficient fibre coupling, individual lenslets were required to be aligned with the centre of the fibre core with an accuracy of 5 microns. The lenslet array has been fabricated over the surface of a glass plate (S-FPL51 glass, from Ohara Glasses) of thickness 10.8 mm. This glass plate is used as a buffer between lenslets and fibre. A fabrication setup was developed in the instrumentation laboratory at IUCAA. In this set up a laser is made to fall perpendicular to the surface of the glass plate and fibre cores. The fibre bundle was back illuminated and the laser could be aligned with any of the fibre cores with the translations of two motorized linear stages. UV curing optical cement was applied to the plane surface of individual lenslets which were then fixed to the front surface of the glass plate, after aligning them with the relevant fibre core. Figure 24 shows the setup used and the fabricated lenslet array.

Output Optics: At the output, the fibres are aligned along a one dimensional slit and the output optics is used to couple this fibre slit to the spectrograph. The output optics consists of two singlet lenses and an achromatic doublet lens.

The mechanical layout of the IFU is divided in to two parts, namely, the front unit and the output optics mechanical assembly. The front unit is the mechanical interface between the IFU and the telescope. It is mounted on one of the side ports of the telescope and provide mechanical support for the fore-optics, section of the IFU. It carries the three achromatic doublet lenses of the fore-optics as well as the lenslet array IFU-iras-spectra along with the front end of the fibres. A flat mirror is used to fold the optics as the space available outside the side port is not enough for a linear design. Further, provision for calibration lamps is also made on this unit, for wavelength calibration of the observed spectra. Light from these lamps is fed to the fore-optics section of the IFU using a pneumaticaly actuated second fold mirror, which also blocks the light from the telescope. The front-unit has been designed and developed using off the shelf space frame components from LINOS Photonics, Germany. The mechanical structure of this front unit is shown in Figure 25.

Output optics mechanical assembly is the mechanical interface that integrate the output optics within the existing IFOSC calibration unit on the telescope. The calibration unit contains two wheels that are driven by stepper motors. The output optics assembly consists of three parts: (1) Main body that contains first two lenses of the output optics. The fibre slit unit is coupled to output optics through this part. It is mounted on the wall of the calibration unit; (2) Fold mirror mount is a mechanical assembly to fix a fold mirror at 45 degree. It is mounted on one of the two filter wheels inside the calibration unit and (3) Lens mount, to hold third lens of the oOutput optics. It is fixed to the other filter wheel inside the calibration unit.

The front unit is mounted on the IUCAA Girawali Observatory (IGO) telescope's side port and the output optics is aligned with the IFOSC's optic axis. These two parts are joined together by the fibre units assembly (Figure 26). The projected fibre slit is shown in Figure 27. Figure 28 shows a lamp spectra taken with FIFUI.

FIFUI was installed on the telescope by late 2009. Instrument commisioning and on-sky performance verification tests were carried out during November 2009 to January 2010. As FIFUI is developed to be a part of a pre-existing setup, its performance is highly coupled to the functioning of the telescope and IFOSC. Firstly, the IFU footprint on the IFOSC CCD was to be determined, for each of the sampling scales. This has been done by mapping individual fibre cores to the pixels of IFOSC CCD. Determining these footprints are essential to allow bringing the target object within the IFU field of view. The commissioning of the IFU on IGO telescope involved several sky tests. In particular, it involved the determination of the following issues:

* As the IFU is mounted on one of the side ports of the telescope, the relation between normal IFOSC focus position and IFU focus position was required to be calibrated for different sampling scales of the IFU. These offsets have been determined by moving the secondary mirror of the telescope, for each of the three sampling scales and looking at the PSF of stellar images on the IFU. The estimates have been found to be very consistent with the designed values.

* The relative pointing offsets for the three sampling schemes were calculated by determining the positions of a point source (a star) on the IFU input (i.e., on the surface of lenslet array) and respective positions on the IFOSC.

* The IFU mode throughput and sensitivity was determined by observing standard stars both with IFU assisted IFOSC and then with IFOSC only.

* The flat field observations through IFU were used to determine fibre to fibre response calibration.

The commissioning observations/tests played a very critical role in defining the strategy for integral field observations on IGO telescope. Further, it provided several required inputs, as discussed above, for the development of spectral flat fielding, wavelength calibration, spectral extraction strategies and IFU data cube generation. As 8 out of 100 IFU fibres turned out to be non-functioning (broken or low throughput), this leaves gaps in the integral field observations of the 2-D field being observed. However, these gaps could be filled by giving appropriate pointing offsets in the repeated

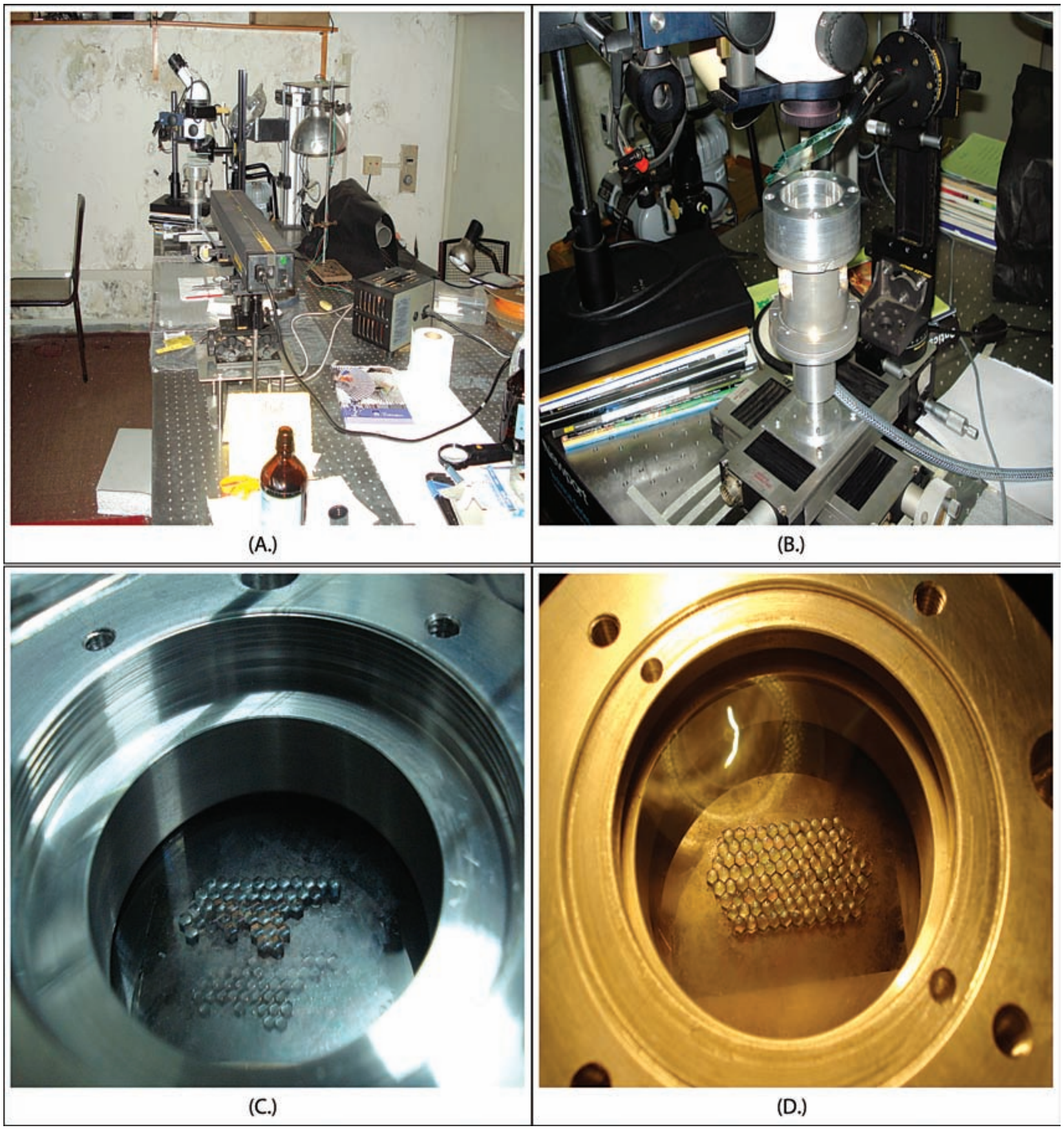


Figure 24: Figures showing various stages in the fabrication of *lenslet* array. (A) Laboratory setup used for lenslet array fabrication, (B) Mechanical units to hold fibre bundle and lenset array, (C) Lenslet array during fabrication and (D) Complete lenslet array.

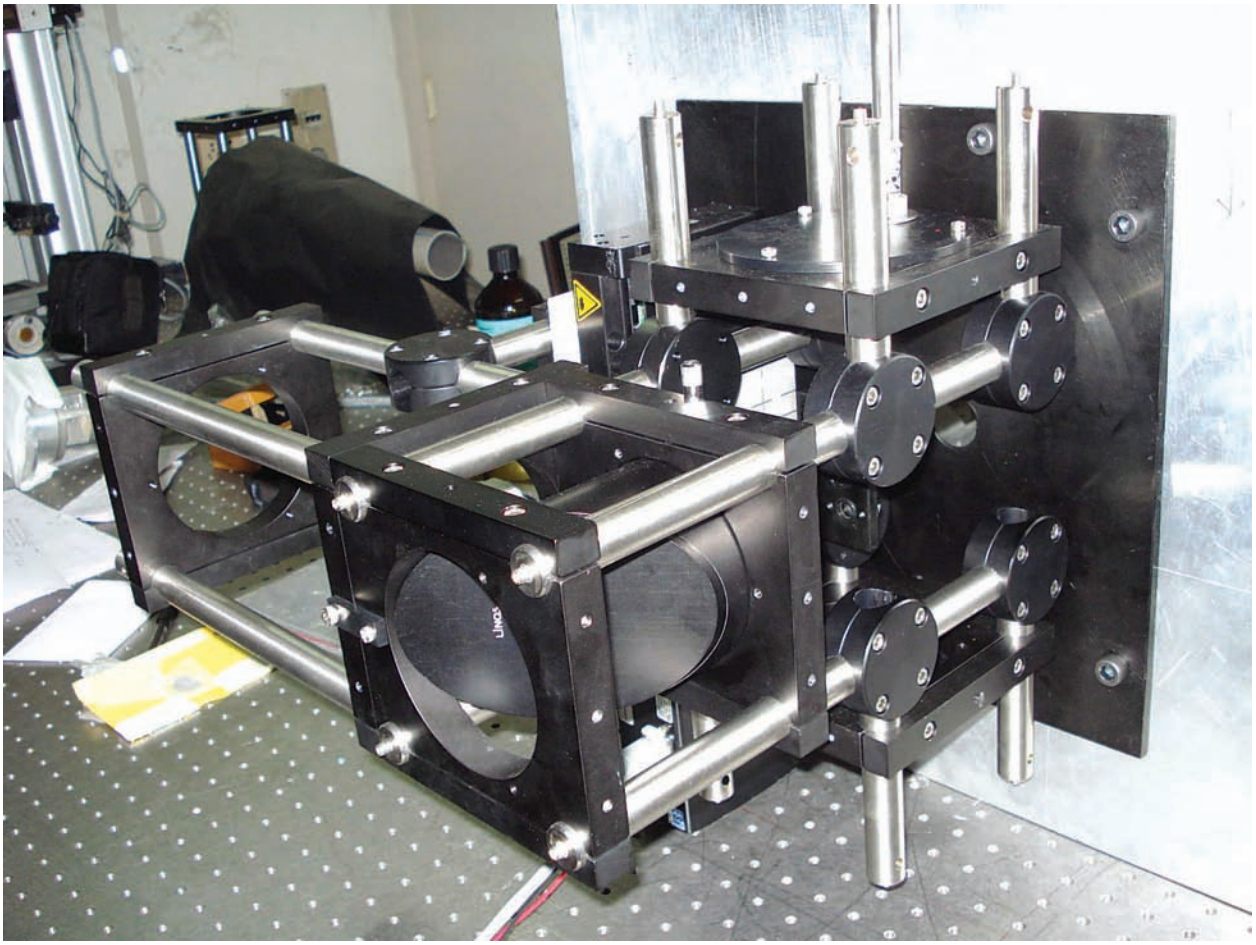


Figure 25: IFU front unit in the laboratory.

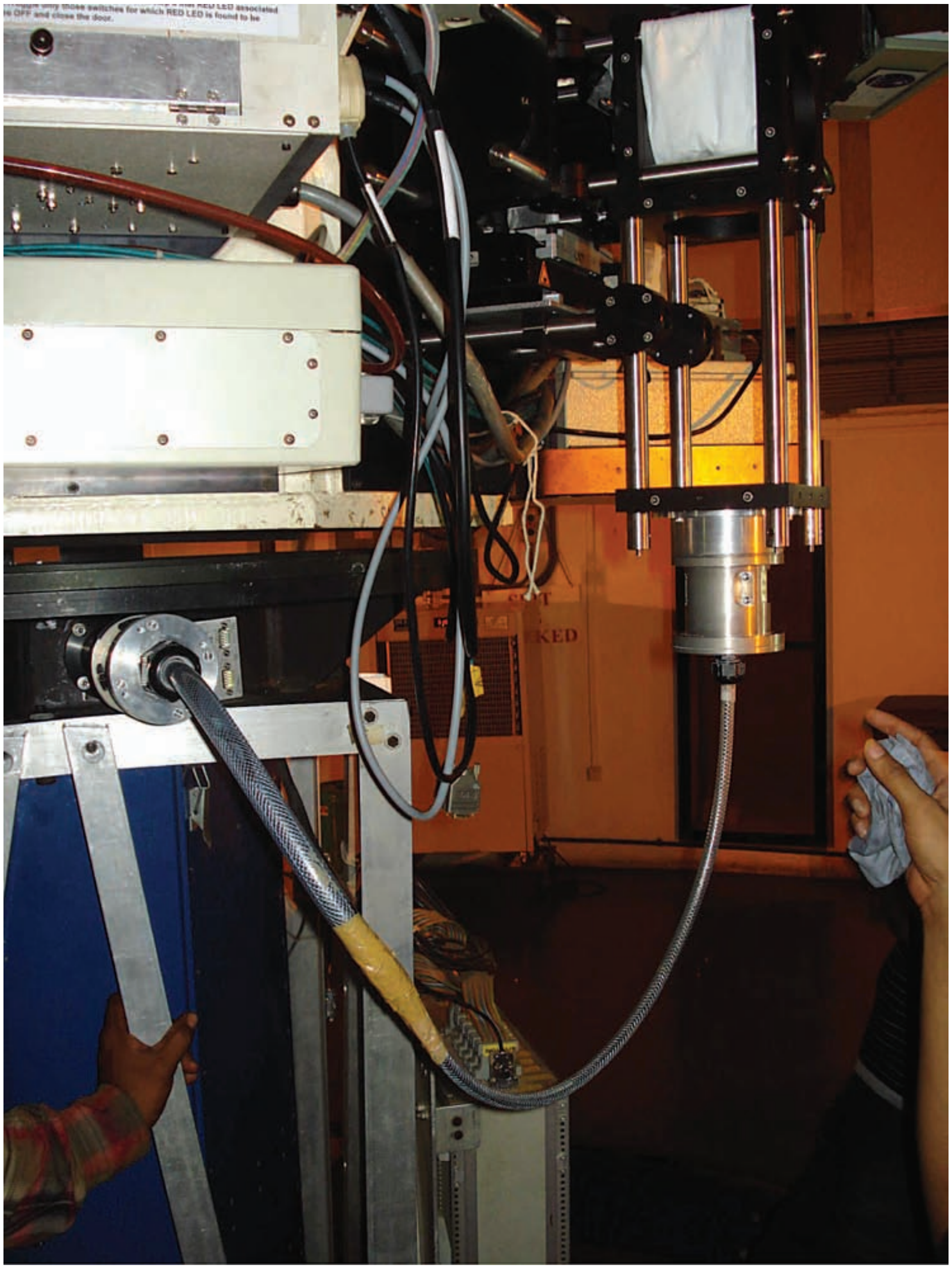


Figure 26: IFU mounted on one of the side ports of the IGO telescope.

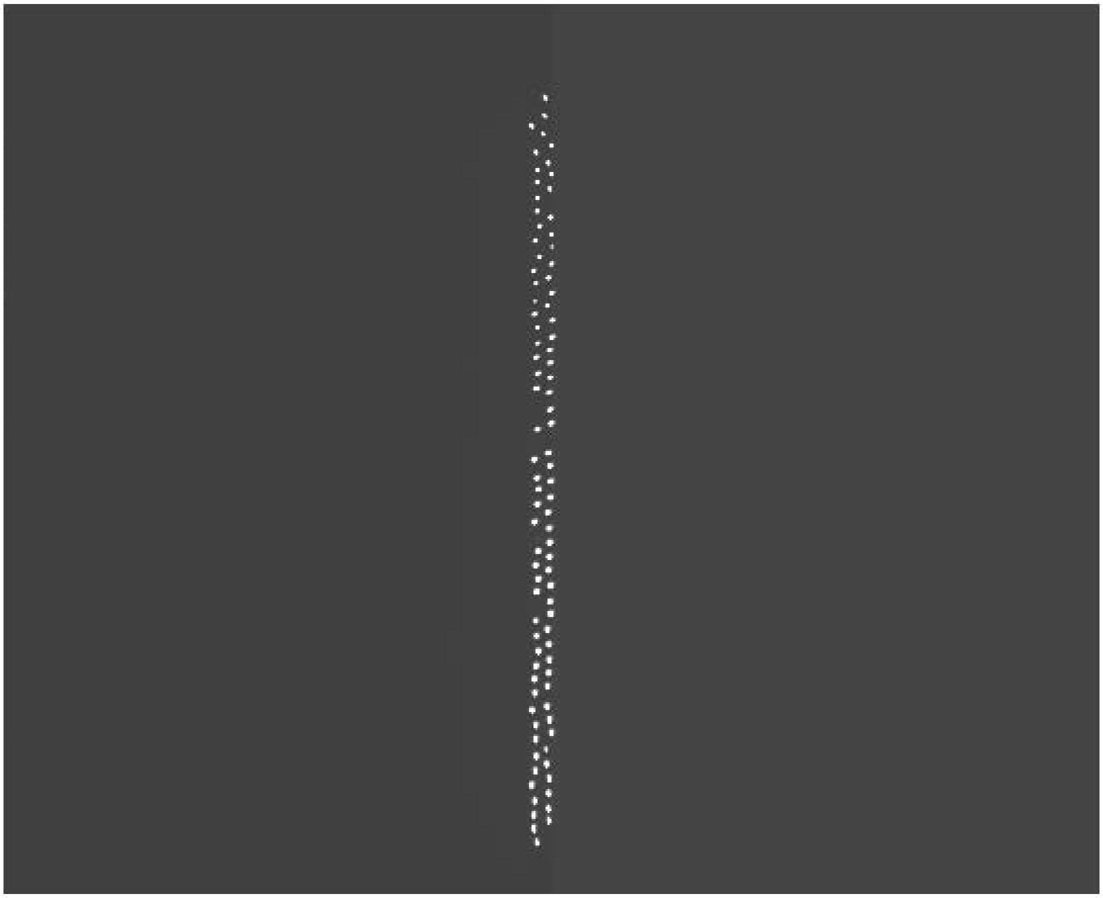


Figure 27: The IFU fibre slit: The fibres are arranged in two parallel slits with an offset in the vertical direction. Eight fibres of the fibre unit were not functioning.

observations of the field of view.

The IFU is optimized for the visible spectrum and light from individual fibre cores (pseudo slits) would be dispersed by IFOSC. Thus, the spectral resolution and wavelength coverage provided by FIFUI would be determined by the projected width of the fibre cores and the grism used. The projected fibre slit on the IFOSC entrance is measured to be ∼ 2.2 arcsec. Further, within IFOSC, IFORS1 (3300 - 5540 $\AA$), IFOSC7 (3800 - 6840 $\AA$) and IFOSC8 (5800 - 8350 $\AA$) grisms all together cover the whole visible range relevant to IFU observations. With slit width of 2.2 arcsec, they provide spectral resolutions of 8 - 10 $\AA$. For IFU-iras-spectra science verification programme, integral field spectroscopy of a sample of Ultra Luminous Infrared Galaxies (ULIRGs) has been done. Most of these objects are merging systems having double nuclei and complex kinematics in the central regions. Further, the angular dimensions of these objects ($\sim 15 \times 10\, arcsec$) make them ideal candidates for science verifications of the IFU. Further, it has been found that ULIRGs are merging system of gas rich galaxies with most of the active regions are enshrouded in dust, thus, the morphology and gas kinematics could be traced by Hα emission from this warm ionized gas. As the selected ULIRGs are at redshift ∼0.05 and having surface brightness ∼17-20 magnitude per arcsec^2, several observations of ∼ 45 minutes exposures had been taken. A set of predetermined pointing offsets were given between successive observations to fill the gaps in IFU input due to inactive fibres. Also, as the aim was to trace Hα emission, IFOSC8 grism was used, since, it offers the required wavelength range. Sky emission was determined by nod and shuffle method and calibration spectra were taken just before and after the science observations. A section of CCD data frame with IFU spectra of an ultra-luminous infrared galaxy IRAS 12540+5708 for 45 minutes exposure is shown in Figure 29.

Reduction of IFU data is a complex process and an analysis pipeline is currently under development for FIFUI. General IFS data reduction includes (a) identification of position of the spectra on the detector, (b) determination and subtraction of scattered light, (c) extraction of each individual spectrum, (d) dispersion correction, (e) fibre to fibre response correction, (f) flux calibration, and (g) subtraction of sky emission. Finally, in order to reconstruct the image of the object, the spectra are to be reordered on their original location in the sky. Moreover, correction of differential atmospheric refraction is required to be done. However, data reduction for IFU on IFU-iras-spectra IGO telescope offers some unique challenges as compared to several existing integral field spectrograph on other telescopes. Due to its design, all the fibres in the pseudo slit are not along a single column, rather they are distributed in two columns with an offset along the spectral direction. Further, the fibre pseudo slit is re-imaged on the IFOSC slit plane using some coupling optics and due to optical aberrations, individual fibre cores are aberration dominated and are not identical. These two issues puts additional constraints over wavelength calibration of the spectra and are to be dealt with extreme care while reducing the IFU data.

This work formed the Ph.D. thesis of **Mudit K. Srivastava**, under the guidance of **A. N. Ramaprakash**.

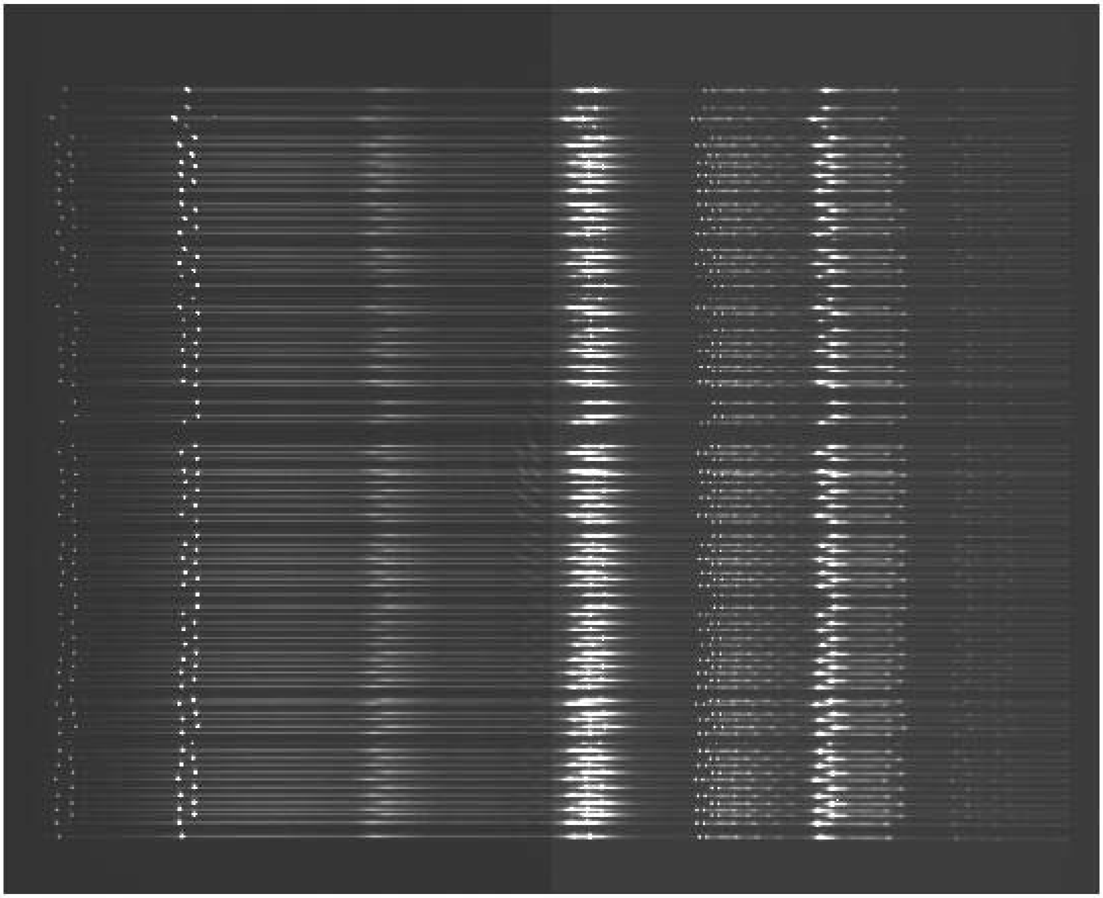


Figure 28: The IFU spectra : Spectra of a lamp taken with IFU assisted IFOSC

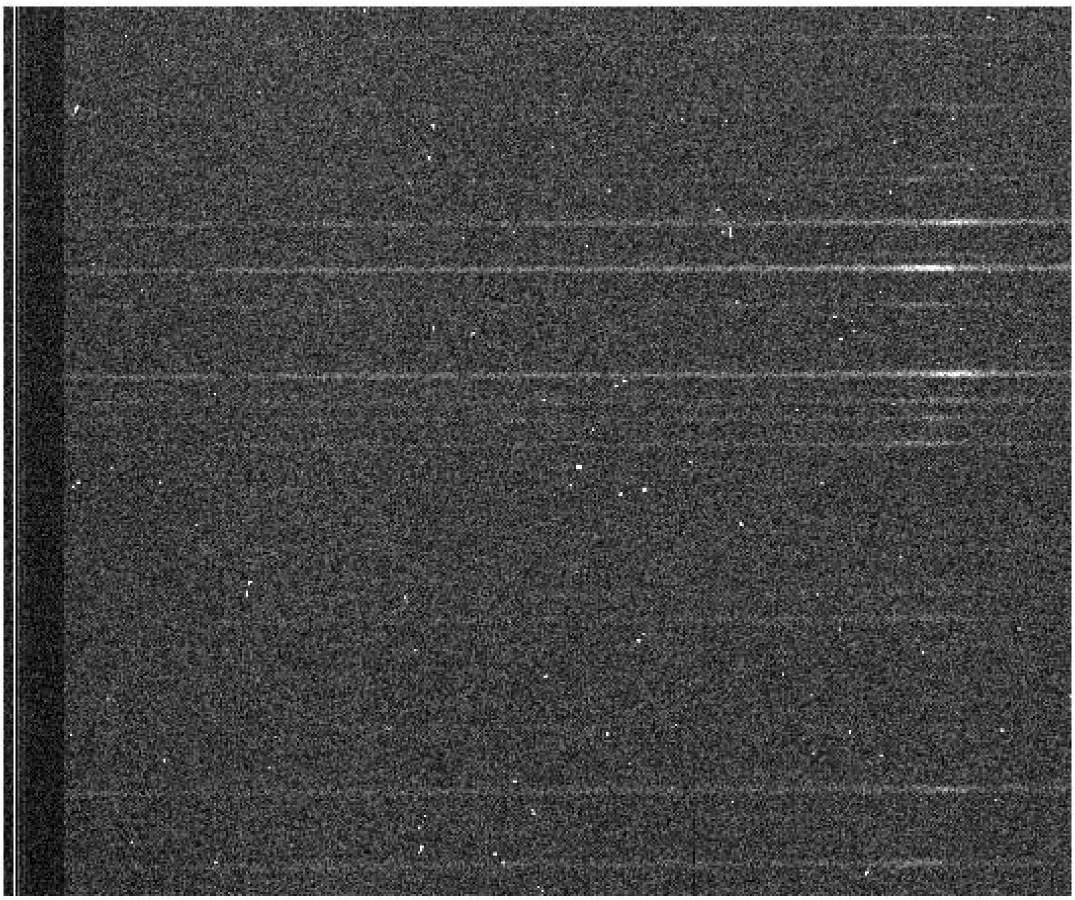


Figure 29: The IFU spectra of an ultra-luminous infrared galaxy IRAS 12540+5708 for 45 minutes exposure.

(II) RESEARCH BY VISITING ASSOCIATES

Cosmic Microwave Background

Sanjay Jhingan

The fluctuations in Cosmic Microwave Background (CMB) contain an amazing amount of information about our universe. Detailed measurements of anisotropy in the CMB reveal global properties, constituents and history of the universe. In standard cosmology, CMB anisotropy is assumed to be statistically isotropic and Gaussian. Deviations from statistical isotropy can be modeled in various ways, for instance, anisotropic cosmological models (Bianchi models), compact topologies and presence of primordial magnetic field. Signature of anisotropy manifests itself in CMB correlation pattern.

Jhingan has studied measures of Statistical Isotropy (SI) violation to the reduced symmetries of the underlying correlation patterns in the CMB map or the correlation function. This work has been done with T. Souradeep, Nidhi Joshi and A. Hajian. They have presented illustrative examples of the symmetries from various mechanisms of SI violation. Defining, within the framework of Bipolar harmonic representation of CMB sky maps, a number of observables that can be used to quantitatively test SI. A study of the properties of bipolar measures as one systematically reduces the rotational symmetries of the CMB correlations, as is expected in different theoretical scenarios, has been presented.

Manzoor A. Malik

Manzoor A. Malik has initiated some work in CMB research with Tarun Souradeep. This work will largely hinge around constraining the cosmological parameters and the underlying theoretical models with CMB anisotropy and polarization measurements. The idea is to make advance preparation for the 2012 public release of Planck data, as well as to expand the sphere of influence of CMB research in India. Malik has also made new contributions to the cosmological many-body problem that includes formulation of the distribution function for a two-component system of galaxies with extended structures.

Pranjal Trivedi

In collaboration with T. R. Seshadri and K. Subramanian, Pranjal Trivedi has been studying the effects of primordial cosmic magnetic fields on the cosmic microwave background radiation. The bispectrum, or the three-point correlation function of the CMB in harmonic space, is a measure of its non-Gaussian fluctuations. Primordial stochastic magnetic fields contribute at lowest order to non-Gaussian signals and can make a significant contribution to the observed CMB bispectrum. The calculation of the theoretical CMB bispectrum due to magnetic fields for the passive scalar and vector modes has been studied. This can improve upper limit constraints on the strength of the primordial cosmic magnetic field by comparison with the current observations of non-Gaussianity in the CMB.

Mathematical and Theoretical Physics

Suresh Chandra

Suresh Chandra and his research group have been working in the field of solar physics. They have investigated the propagation of MHD waves in homogeneous solar plasma. There has been a long lasting controversy about the degree of polynomial for the dispersion relation. They have sorted out this discrepancy by showing explicitly that five roots of the two versions of dispersion relation are common and the sixth root, having no physical significance, was introduced by one group, which has been claiming that the degree of polynomial must be six and not five. Though five roots of two expressions have been found common, the reason for the difference in their results is still ambiguous.

Pradip Mukherjee

Pradip Mukerjee (with Anirban Saha) has studied the relationships between re-parametrization and gauge symmetries of the second order metric gravity theory from a new Hamiltonian approach which follows Dirac's method of constrained Hamiltonian analysis.

Along with Rabin Banerjee, Subir Ghosh, Biswajit Chakraborty and Sourav Samanta, Mukherjee has reviewed certain topics of non-commutative geometry inspired physics. Also, along with Rabin Banerjee, Sunandan Gangopadhyay and Debraj Roy, he has thoroughly investigated the symmetries of 3-dimensional gravity with torsion in the Poincare Gauge Theory framework.

Further, Mukherjee has studied the construction of Poincare Gauge Theory starting from higher derivative matter Lagrangian.

P.N. Pandita

One of the most important predictions of locally supersymemtric theories is the existence of the gravitino, the gauge fermion of supergravity. Its discovery would be of fundamental importance.

There are several models of supersymmetry breaking. Depending on the model, the gravitino can be the lightest superparticle (LSP). Thus, gravitino in this case can be a natural dark matter candidate. It would be important to discover a massive gravitino and to establish spontaneously broken local supersymmetry as a fundamental symmetry of nature.

P.N. Pandita has been investigating some of the aspects of gravitino as a dark matter candidate. Although, gravitino LSP is consistent with observation, the cosmology of next-to-lightest supersymmetric particle (NLSP) is problematic. In models with R-parity conservation, the NLSP can only decay to gravitino and standard model particles with a rate supppressed by the Planck mass. As a result, NLSP is present in the universe at the time of bing bang nucleosynthesis, thereby, affecting the successful predictions of the standard nucleosynthesis scenario. Several models have been proposed to circumvent this difficulty, but the simplest one is based on the assumption that R-parity is not conserved. If R-parity is mildly violated, the NLSP decays into standard model particles well before first nucleosynthesis reactions take place, thereby, avoiding any conflict with the standard nucleosynthesis predictions. In such a scenario, gravitino decays could be happening at sufficiently high rate for decay products to be detectable in experiments.

P.N. Pandita has been investigating gravitino decay into photons, as well as other stable particles, such as electrons, protons, neutrinos, and their antiparticles. If the gravitino is lighter than $W^{\pm}$ bosons, it decays mainly into a photon and a neutrino. On the other hand, if the gravitino is heavier than the $W^{\pm}$ or Z^0 bosons, new decay modes are open. These decay modes depend upon the photino-neutrino mixing, and on charged-wino–charged-lepton mixing. These mixings depend, through gaugino masses, on the boundary conditions at the grand unified scale. Different grand unified gauge groups have been considered, and the branching ratios to various channels have been calculated. The implications of these results for the gravitino as a cold dark matter have been studied in detail.

Anirban Saha

There are theoretical motivations of spacetime structure following a noncommutative (NC) algebra and in recent years, a lot has been done to build quantum mechanical, as well as field theoretic framework on such a spacetime. Apart from studying the formal aspects of the NC geometry, certain possible phenomenological consequences have also been investigated. A part of the endeavour is spent in finding the order of various NC parameters and in exploring its connection with observations.

Anirban Saha has earlier proposed a field theoretic starting point for studying the effect of time-space noncommutativity on one such experimental setup, namely, the study of the energy spectrum of gravitationally bound cold neutrons in the GRANIT experiment. He has pursued this work by studying the Galilean invariance of his field theoretic model. A thorough analysis of Galilean symmetries on a noncommutative plane has been done. A complete closure of the one-parameter centrally

extended Galilean algebra is realized for the model. This implies that the field theoretic model constructed to describe noncommutative gravitational quantum well is indeed independent of the coordinate choice. Hence, the energy spectrum predicted by the model can be associated with the experimental results to establish the upper-bound on time-space noncommutative parameter.
Such upper-bounds on various NC parameters suggest that the tiny length-scale, where noncommutative nature spacetime will make its presence felt is quite close to that in which, the gravitational wave detectors operate. Therefore, Saha, along with his collaborator Sunandan Gangopadhyay has started formulating the NC quantum mechanical analysis of some simplistic models (e.g., free particle, simple harmonic oscillator) describing the interaction of gravitational wave with matter.

Also, Saha, together with his collaborator Saurav Bhattacharya, has shown that a particle, with positive orbital angular momentum, following an outgoing null/timelike geodesic, shall never reach the closed timelike horizon present in the $(4+1)$-dimensional rotating Gdel black hole spacetime. Therefore, a large part of this spacetime remains inaccessible to a large class of geodesic observers, depending on the conserved quantities associated with them. They have discussed how this fact and the existence of the closed timelike curves present in the asymptotic region make the quantum field theoretic study of the Hawking radiation, where the asymptotic observer states are a pre-requisite, unclear. However, the semi classical approach provides an alternative to verify the Smarr formula, derived recently for the rotating Gdel black hole. A systematic analysis of particle emissions, specifically for scalars, charged Dirac spinors and vectors, from this black hole have been presented via the semi classical complex path method.

Stars and Interstellar Medium

Suresh Chandra

Suresh Chandra and his group have been also working in the field of anomalous absorption in molecules in the cool cosmic objects. The anomalous absorption, where the brightness temperature of a line becomes smaller than the temperature of the cosmic microwave background, is an unusual phenomenon. The investigation requires solving a set of statistical equilibrium equations coupled with the equations of radiative transfer. Here, one of the input parameters is the collisional rates. For calculating the collisional rates, one requires the interaction potential between the molecule and the colliding partner. The work for calculation of interaction potential for H_2CS colliding with He atom has been completed. This interaction potential will be used in the software MOLSCAT. For execution of MOLSCAT, they are going to use the High Performance Computing Facility available at IUCAA.

Ajay Chaudhari

Interstellar molecules play an active role in the energy balance of clouds. Until now, more than 170 molecules have been identified in astronomical environment, such as interstellar clouds, planetary nebulae, circumstellar envelopes, stellar atmospheres and comets. It is expected that many more interstellar molecules will be discovered in space, once their characteristic spectra are known. Therefore, it is necessary to have knowledge of spectroscopic characterization of the molecules. Methylamine is one of the important molecules for the production of H3+ ion in interstellar and star forming regions. A. Chaudhuri has predicted vibrational and absorption spectra of methylamine molecule using quantum chemical methods. Effect of ionization of methylamine on its vibrational and absorption spectra has been also studied. This result should provide useful guidelines to detect this molecule and its ions in space and will help in the interpretation and analysis of observational data obtained for methylamine and its ions in different environment.

Sanjay K. Pandey

Turbulence plays an important role in determining the physical conditions of the neutral inter stellar medium (ISM) and the hierarchy of the structures seen in it. As there is no preferred length scale in turbulence, so in general, it can follow only a power law. If the physical process involved is fully random then we can completely infer the process from its power spectrum. But, if there is a finite amount of non-Gaussianity mixed, it cannot be fully understood by power spectrum measurement alone. One needs the bispectrum, which will be zero if the physical process involved is completely Gaussian. S.K. Pandey has used this methodology in the case of an almost a face-on type Sc galaxy NGC 1058, which is at redshift z = 0.0017. The archival HI data is used for this galaxy from VLA to estimate bispectrum and got preliminary results related to this. To increase signal to noise ratio, he has averaged the correlations in bins of baselines and over frequency channels with HI emission.

Ninan S. Philip

N.S. Philip along with S. Abraham has investigated the disparities in the spectroscopic and photometric classifications of objects in the Sloan Digital Sky Survey (SDSS) using machine learning tools. The emphasis of the study was to improvise photometric classification methods to the accuracies attainable using spectroscopy. Spectroscopy is more accurate than photometric classifications. However, because of the very fact that it is done by scattering a beam of light along a line on the basis of its wavelength, the intensity of light falling on each pixel of the detector will be that much fainter. This limits spectroscopic classification to bright objects in the sky. Photometry, on the other hand, allows a band of wavelengths to pass through a filter and produces that much intense image on the detector. However, this loss of resolution averages out the intensities of specific emission or absorption lines that helps classification. Minimizing this trade off is the challenge.

SDSS has five filters and astronomers have shown over the years that the difference in the light flux in the filters, which they call colour, can give a good deal of information about the nature and type of an object. Philip and Abraham have used this method using a tool called Difference Boosting Neural Network, and studied the failures in detail by looking at individual images and their spectra. They have found that many of the objects that failed classification were exotic in nature, like quasars with broad absorption lines (BAL), binary quasars, Seyfert galaxies with very strong emission lines, etc. This identification helped them to fine tune their machine learning algorithm to reduce disparity in the classifications by the two methods to less than 1%. In addition, they were also able to detect about 300 spectroscopic classification errors in SDSS data.

As mentioned before, one of the advantages of the scheme is that it is possible to go to fainter levels of magnitude with photometry. Thus, they have prepared a catalogue of about 3 million quasars that have SDSS I band magnitudes ranging from 17 to 27. This is expected to have a completeness in the redshift range below 3 in this magnitude and is about three times the existing largest quasar catalogue. They are now working on cross matching their SDSS quasars with other surveys like radio, x-ray, etc. to ensure that systematic errors do not show up at the fainter levels. This work has been published.

Shantanu Rastogi

The mid-infrared (IR) emission bands at 3.28, 6.2, 7.7, 8.6 and 11.2 μm, attributed to Polycyclic Aromatic Hydrocarbon (PAH) molecules, show spectral variations in different astrophysical objects that are correlated with shape, size and ionization state of PAHs surviving in these objects. Quantum chemical calculations of IR features of a large number of PAHs are carried out using the HPC facility at IUCAA. Model composite IR emission by these PAHs compare well with observations of the 7.7 μm feature pointing towards large PAHs in the outflows of post-AGB stars with only compact medium sized PAHs surviving in strong UV sources. But the 6.2 μm band is obtained at lower frequency for most PAHs. So a study of PAHs with vinyl side groups is being done. The most suitable basis for calculations and frequency scaling procedures are identified using matrix isolated IR spectra of vinyl-anthracenes. In the composite spectra of a few vinyl-PAHs, the 6.2 μm mode is found to shift closer to the observed features characterized as type C.

The extinction properties of nanodiamonds/nanodiamonds as core in different carbon metamorphs are studied using discrete dipole approximation. The 220 nm absorption bump is modified along with a strong far-UV rise in extinction. Incorporating nanodiamonds in dust models show better match with the average galactic extinction. Extinction models incorporating nanodiamonds along anomalous sightlines that show very strong far-UV rise have been attempted. Preliminary results along a few objects show better extinction match and also reduce the use of silicates that satisfies the ISM abundance pattern.

Asoke Kumar Sen

The optical polarimetry data of two star forming clouds CB3 and CB246, as observed in the past by using IUCAA Imaging Polarimeter (IMPOL) and 1.2 m IR telescope at Mount Abu were studied in detail by Asoke K. Sen and his collaborators (Ward-Thompson and others) from the star formation group at Cardiff University, UK. These optical polarimetry data were combined with the sub mm polarimetry data observed from JCMT, Hawai by Cardiff star formation group. Each set of polarimetry data was used to infer the magnetic field orientation in each of the clouds. The optical data can only trace the field orientation in the low-density edge regions of clouds, because if the extinction is too high then no optical emission is transmitted. Further, the sub mm data can only trace the field orientation in the high-density central regions of the clouds, because current sub mm polarimeters are only sensitive to high column densities. It has previously been reported that the near-infrared polarization mapping of background stars does not accurately trace the magnetic field in dense cloud regions, which may be due to lack of aligned grains in dense regions. However, the authors found that the field orientation deduced from the optical data matches up well with the orientation estimated from the sub mm data. Thus, it was found that both methods accurately trace the same magnetic field in the two clouds.
Further, the offset angle between the magnetic field orientation and the short axis of the globule CB3 and CB246 were found to be consistent with the mean value suggested by the authors in their work on pre-stellar cores.

T.R. Seshadri

With Sukanta Deb, S. K. Tiwari, H. P. Singh and U. S. Chaubey, T. R. Seshadri has worked on the B band photometric analysis of the Scuti star HD 40372 on the basis of the data obtained from the Sampurnananda Telescope, ARIES. The period is found to be 0.067 days and that it is pulsating in p-mode with an $l = 2$.

H.P. Singh

Ongoing and future surveys of variable stars will require new techniques to analyse their light curves, as well as to tag objects according to their variability class in an automated way. H. P. Singh and S. Deb have made use of principal component analysis (PCA) and Fourier decomposition (FD) method as tools for variable star light curve analysis and compared their relative performance in studying the changes in the light curve structures of pulsating Cepheids and in the classification of variable stars. They have calculated the Fourier parameters of 17 606 light curves of a variety of variables, e.g., RR Lyraes, Cepheids, Mira Variables and extrinsic variables for their analysis. They have also performed PCA on the same database of light curves. The inputs to the PCA were the 100 values of the magnitudes for each of these 17 606 light curves in the database interpolated between phase 0 to 1. Unlike some previous studies, Fourier coefficients were not used as input to the PCA. They have shown that in general, the first few principal components (PCs) are enough to reconstruct the original light curves compared to the FD method, where two to three times more parameters are required to satisfactorily reconstruct the light curves. The computation of the required number of Fourier parameters on average needs 20 times more CPU time than the computation of the required number of PCs. Therefore, PCA does have some advantages over the FD method in analysing the variable stars in a larger database. However, in some cases, particularly in finding the resonances in fundamental mode (FU) Cepheids, the PCA results show no distinct advantages over the FD method. It was demonstrated that the PCA technique can be used to classify variables into different variability classes in an automated, unsupervised way, a feature that has immense potential for larger databases in the future.

They have also done a careful and detailed light curve analysis of RR Lyrae stars in the Small Magellanic Cloud (SMC), discovered by the Optical Gravitational Lensing Experiment (OGLE) project. Out of 536 single-mode RR Lyrae stars selected from the data base, they have investigated the physical properties of 335 'normal-looking' RRab stars and 17 RRc stars that have good quality photometric light curves. They have also estimated the distance modulus of the cloud, which is in good agreement with those determined from other independent methods. Accurate Fourier decomposition parameters of 536 RR Lyrae stars in the OGLE-II data base were computed. Empirical relations between the Fourier parameters and some physical parameters of these variables have been used to estimate the physical parameters for the stars from the Fourier analysis. Further, the Fourier decomposition of the light curves of the SMC RR Lyrae stars yields their mean physical parameters as MV = 0.78 +/- 0.02 for 335 RRab variables and MV = 0.76 +/- 0.05 for 17 RRc stars. Using the absolute magnitude together with the mean magnitude, intensity-weighted mean magnitude and the phase-weighted mean magnitude of the RR Lyrae stars, the mean distance modulus to the SMC is estimated to be 18.86 +/- 0.01, 18.83 +/- 0.01 and 18.84 +/- 0.01 mag, respectively, from the RRab stars. From the RRc stars, the corresponding distance modulus values are found to be 18.92 +/- 0.04, 18.89 +/- 0.04 and 18.89 +/- 0.04 mag, respectively.

Nonlinear Dynamics

Ambika G.

Natural systems are highly complex since their dynamics involve a large number of variables and highly nonlinear interactions. Hence, studies related to their dynamics most often rely on a sequence of observations or data of a few variables. Such time series are then used to detect nontrivial structures and characterize them for a proper understanding of the underlying dynamics. Such studies are very important in complex systems of nature like stars, black holes, climatic systems, etc. since, that is the only information available about them and understanding their dynamics using such time series is an area of active research in recent times.

Ambika has recently done significant work in this direction on quantifying complexity in such systems with relevant measures using their time series. Along with her collaborators R. Misra and K. P. Harikrishnan, an automated algorithm has been developed for computing multifractal measures that fix the geometric complexity of the reconstructed attractor from the time series. These studies that map the spectrum to that of a Cantor set, supplies three parameters that characterize the dynamic processes leading to the mutifractal. Their work leads to a parametric characterization of multifractal spectra using minimum relevant quantifiers related to an underlying dynamics. These quantifiers will serve as better tools for diagnostic purposes for data like EEG and ECG.

Synchronization of nonlinear chaotic systems has been achieved by different coupling schemes and the various states of synchronization, characterized as phase/anti-phase, lag, anticipatory and identical, have been explored in many real world systems. Recently, Ambika has introduced a new coupling scheme for synchronising two chaotic systems, in which only intermittent information from the driving system is needed to synchronise the response. This led to a new theory of stability analysis and Lyapunov exponents for such couplings. This work has been done in collaboration with R. E. Amritkar and it has immense potential in applications like secure communication, where the key space is enhanced by the extra parameters in the coupling scheme.

Recently, Ambika has reported the study of environmental coupling in chaotic systems, which leads to phase (anti-phase or in phase depending on the nature of coupling) synchronization. Here, the systems are not directly coupled and therefore, retain the features of individual systems even after coupling. This is relevant in the context of biological systems, where the coupling can be due to chemicals in the surrounding medium.

K.P. Harikrishnan

K. P. Harikrishnan, in collaboration with R. Misra, G. Ambika and R. E. Amritkar, has proposed an automated algorithmic scheme for the computation of generalized dimensions and multifractal spectrum for any embedding dimension from time series data. The scheme is first tested with the time series from logistic attractor with known multifractal spectrum and subsequently applied to higher dimensional cases. They have also shown that the scheme can be effectively adapted for analyzing practical time series involving noise with examples from real world systems.

As an extension of this work, Harikrishnan and collaborators have further shown that any multifractal chaotic attractor can be characterized in terms of the parameters of a two scale Cantor set. The method depends on mapping the multifractal spectrum of a chaotic attractor on to that of a two scale Cantor measure. The analysis also shows that the multifractal characterization gives information only up to two scales.

V.C. Kuriakose

Self-writing is a new and emerging area in nonlinear optics. V.C. Kuriakose and collaborators have performed an experiment to observe self-written waveguide inside a bulk methylene blue sensitized poly/vinyl alcohol/acrylamide photopolymer material. Light from a low power HeNe laser is focused into the material, and the evolution of the beam is monitored. The refractive index of the material is modulated in the region of high intensity due to photobleaching and photopolymerization effects occurring in the material. We have observed that under these conditions, the beam propagates through the medium without any diffraction effects. We have developed a theoretical model to explain the experimental observation and there is good agreement between theoretical predictions and experimental observations.

H.P. Singh

H.P. Singh and collaborators V. Suyal and A. Prasad have performed nonlinear analysis of sunspot number time series using the Hurst exponent. They have used the rescaled range analysis to estimate the Hurst exponent for 259-year and 11 360-year sunspot data. The results show a varying degree of persistence over shorter and longer time scales corresponding to distinct values of the Hurst exponent. They have explained the presence of these multiple Hurst exponents by their resemblance to the deterministic chaotic attractors having multiple centres of rotation.

Classical and Quantum Cosmology

Subenoy Chakraborty

S. Chakraborty, in collaboration with T. Bandyopadhyay, has investigated the thermodynamics of the universe filled with modified Chaplygin gas, considering the integrability condition of the laws of thermodynamics. Using the asymptotic analysis, they have shown that the thermal evolution of the universe from radiation era to cold dark matter (CDM) model. Also, they have examined the thermodynamic stability of the universe filled with modified Chaplygin gas and have not obtained any critical point indicating no phase transition.

Considering universe as bounded by the event horizon as a thermodynamical system, S. Chakraborty in collaboration with N. Mazumder, has examined the validity of the generalized second law of thermodynamics (GSLT) in the holographic dark energy model. For homogeneous and isotropic model of the universe, the matter is chosen in the form of non-interacting two fluid system: one component is the holographic dark energy and the other component is in the form of dust. They have found that if the weak energy condition is satisfied by the holographic dark energy component and first law of thermodynamics is assumed then GSLT is valid on the event horizon and it does not depend on whether the universe is in accelerating or decelerating phase. Further, they have examined the validity of GSLT for both in Einstein gravity as well as in Gauss Bonnet gravity for universe containing perfect fluid with arbitrary equation of state . They have shown that for closed model, validity of GSLT is possible without satisfying weak energy condition, rather imposes an upper bound for the event horizon.

Ujjal Debnath

Ujjal Debnath has investigated a model of the universe containing five components as its constituents and has done the statefinder diagnostics for this model. This model can successfully explain the accelerated expansion of the universe given that it satisfies a certain condition. It has been considered that the modified Chaplygin gas is the dynamically changing part of the dark energy component of our universe. Chaplygin gas provides early deceleration and late time acceleration of the universe. The representation of statefinder parameters shows that the total evolution of the universe starts from radiation era to phantom model.

He has considered a flat Friedmann-Robertson-Walker (FRW) universe filled with dark energy. Instead of considering only one candidate for dark energy, interaction between phantom field and modified Chaplygin gas has been considered. It has been shown that the potential of the phantom field increases from a lower value with evolution of the universe. It has been observed that, the field has an increasing tendency and potential has also an increasing tendency with passage of cosmic time. In the evolution of the universe, the crossing of $w = -1$ has been realized by this interacting model.

A model of the flat FRW universe filled with cold dark matter and Chameleon field is considered, where the scale function is taken as, (i) Intermediate Expansion and (ii) Logamediate Expansion. In both the cases, the expressions of Chameleon field, Chameleon potential, statefinder parameters and slow-roll parameters may be found. Also, it has been shown that the potential always decreases with the Chameleon field in both the scenarios. The nature of slow-roll parameters has been investigated.

Sarbari Guha

Sarbari Guha has studied the motions of test particles in five-dimensional warped product spacetimes. She has also derived the solutions to the Einstein field equations for such spacetimes and analyzed the behaviour of the corresponding four-dimensional universe, which is embedded in the five-dimensional bulk.

With S. Chakraborty, she has considered a five-dimensional warped product spacetime having an exponential warping function, which depends both on time, as well as on the extra coordinates and a non-compact fifth dimension. Assuming that the lapse function may either be a constant or a function of both time and of the extra coordinates, they have studied the nature of the geodesics of test particles and photons, and have analyzed the conditions of stability in this geometrical framework. They have also discussed the possible cosmology of the corresponding (3+1)-dimensional hypersurfaces. The time-dependent warp factor plays an important role in localizing matter to the 4-dimensional hypersurface constituting the observed universe. In another paper, they have determined the nature of modifications produced in the bulk geometry, as well as the consequences on the corresponding braneworld, when the warp factor is in the product form.

With P. Bhattacharya, she has considered a more general kind of a time-dependent warp factor and constructed and solved the five-dimensional field equations for various cases of the warp factor and the extra-dimensional scale factor, starting from very general type of the metric and then reducing down to specific cases. In the low energy regime, a stabilized bulk with constant curvature has been considered, from which the cosmological behaviour of the corresponding observed universe has been interpreted. In the high energy regime, the bulk is assumed to be sourced by an ordinary massless scalar field and thereafter, the type of the scalar field source and the different scale factors have been investigated.

Sanjay Jhingan

The accelerated expansion of the universe is one of the most important discoveries in the cosmology. Whether this observed acceleration is due to some new hypothetical energy component with large negative pressure (dark energy) within the framework of general theory of relativity, or due to modification in the GTR at the cosmological distances (modified gravity), is not known. Therefore, many models have been proposed in literature to understand the origin and nature of this present acceleration.
Among the proposals general relativity is modified to explain the observed acceleration, given by f(R) gravity models, proposed by Hu-Sawicki and Starobinsky are most popular. The large deviations from these models, either result into violation of local gravity constraints or the modifications are not distinguishable from cosmological constant. The curvature singularity in these models is generic but can be avoided provided that proper fine tuning is imposed on the evolution of scalar in the high curvature regime. It is shown that in principle, the problem can be circumvented by incorporating quadratic curvature correction in the Lagrangian, though it might be quite challenging to probe the relevant region numerically. This work has been done in collaboration with I. Thongkool, M. Sami and R. Gannouji.

Kanti Jotania

The problem of the cosmological constant is widely explored, yet remains a puzzle in cosmology. The smallness of the effective cosmological constant, recently observed ($\Lambda_0 \leq 10^{-56}\text{cm}^{-2}$) poses the problems involving cosmology and elementary particle physics theory. The cosmological term Λ is then small at the present epoch simply because, the universe is too old. The problem in this approach is to determine the right dependence of Λ upon R or t.

Some of the recent discussions on the cosmological constant problem and on cosmology with a time-varying cosmological constant by researchers point out that in the absence of any interaction with matter or radiation, the cosmological constant remains a "constant", however, in the presence of interactions with matter or radiation, a solution of Einstein's field equations(EFEs) and the assumed equation of covariant conservation of stress-energy with a time-varying Λ can be found. For these solutions, conservation of energy requires decrease in the energy density of the vacuum component to be compensated by a corresponding increase in the energy density of matter or radiation.
The adequacy of the isotropic universe for describing the present state of the universe is no basis for expecting that it is equally suitable for describing its early stages of evolution. Cosmological models, which are spatially homogeneous but anisotropic have significant roles in describing the universe at its early stages of evolution. Bianchi spacetimes are useful tools in constructing such models. Little attention has been paid towards study of perfect fluid model not satisfying the equation of state. Various cases of locally rotating symmetric Bianchi type I perfect fluid, Bianchi type -VI_0 perfect fluid with free gravitational field and Bianchi type -V perfect fluid cosmological models with heat flow have been considered. In all these cases, it has been found that the cosmological constant Λ is found to be positive and a decreasing function of time, which is supported by results from recent supernovae Ia observations. The physical and geometric properties of spatially homogeneous and anisotropic cosmological models have been discussed.
The motivation to study these cases is to find suitable solution of EFEs/models to describe the evolution of early universe and also study FRW model in general way. In the last case, Jotania has obtained expression for some observable quantities like, look back time redshift, neoclassical test (proper distance $d(z)$), luminosity distance redshift and event horizon (Kinematical tests). He has also obtained

expression for rate of expansion (Hubble paramter (H)) of the universe in different directions and in all cases, the Hubble parameters are time dependent, while the average Hubble parameter is constant. Some of the striking features of this model are : The Bianchi type -V spacetime model gives two type of cosmological models. One with positive value of deceleration parameter indicating the power law expansion of the universe, where as the second one corresponds to exponential expansion of the universe. The power law model represents the singular model, where the spatial scale factors and volume scalar vanish at initial time $t = 0$. The model shows isotropic state in later time of its evolution. The exponential expansion case represents singularity free model of the universe. This also indicates that the universe is too old and has inflationary phase.

B.C. Paul

A composition of normal and exotic matter required to construct a flat emergent universe scenario has been taken up here. Using the observational results from CMBR, BAO peak parameter and taking into account $H(z) - z$ data, B.C. Paul and collaborators have estimated the equation of state (EOS) parameter: $\rho = A\rho - B\rho^{1/2}$. The range of permissible values for the parameters A and B are determined from the observational data. Specifically, they have explored the allowed range of values of the parameter A in the EOS for $B > 0$. They have also compared the magnitude versus redshift obtained in the model with that obtained from the union compilation data.

Saibal Ray

Einstein field equations under spherically symmetric spacetimes have been considered by Saibal Ray and his collaborators in connection with dark energy investigation. A set of solutions is obtained for a kinematic model, without assuming any priori value for the curvature constant and the equation-of-state parameter. Some interesting results, such as the nature of cosmic density and deceleration parameter q, have been obtained with the consideration of two-fluid structure, instead of the usual unifluid cosmological model.

Ray, et al. have presented exact solutions to the Einstein field equations with cosmic string and a space-varying cosmological constant, viz. $\Lambda = \Lambda(r)$, in the energy-momentum tensor. Three cases have been studied: the variable cosmological constant has (1) power law dependence, (2) is proportional to the string fluid density, and (3) is purely a constant. Some cases of interesting physical consequences have been found, where (i) the variable cosmological constant can be represented by a power law of the type $\Lambda = 3r^{-2}$, (ii) the variable cosmological constant and the cosmic string density are interdependent according to the relation $\Lambda = -8\pi\rho_s$, and (iii) the cosmic string density can be scaled by a power law of the type $\rho_s = r^{-2}$. It is also shown that several known solutions can be recovered from the general form of the solutions obtained here. Choosing the three phenomenological models of the dynamical cosmological term Λ, it has been shown by the method of numerical analysis for the considered non-linear differential equations that the three models are equivalent for the flat universe $k = 0$ and for arbitrary non-linear equation of state. A qualitative analysis has been made from the plots which supports the idea of inflation and hence expanding universe.

A.A. Usmani

A.A. Usmani has investigated the various features of the recently proposed brane world model solution. This has been explored focusing, in particular, on the constraints imposed by combined measurements of rotation curve and lensing. Nature of the galactic field has been discussed. Also, stability of circular orbits has been explicitly shown and the attractive nature of gravity in the halo has been established. A brief comparison with a well known scalar field model is also given.

General Relativity and Gravity in Dimensions other than 4

Subenoy Chakraborty

S. Chakraborty in collaboration with T. Bandyopadhyay has studied cosmological solutions in brane-world scenario. Cosmic no-hair conjecture has been examined in the context of Randall-Sundaram II (RS-II) brane world model. Instead of considering the usual anti-de Sitter bulk, a general form of the bulk matter has been taken into account. In order to satisfy the cosmic no-hair conjecture, there are restrictions on the quadratic correction term, as well as on the projected part of the bulk energy-momentum tensor, but the bulk matter need not satisfy the standard energy conditions. Also, considering Gauss-Bonnet gravity in five dimensions without a cosmological constant, they have obtained cosmological solutions for both bulk and the brane. The solutions are found to be consistent with the recent observations.

A thin-shell Lorentzian worm hole with spherical symmetry has been constructed in Einstein-Yang-Mills-Gauss-Bonnet theory. The generalized Darmois-Israel matching conditions are applied to the bounding shell. The amount of exotic matter for the existence of worm hole has been evaluated and it has been shown graphically for certain choices of the parameters involved that ordinary matter is sufficient for the formation of thin shell worm holes. Also Chakraborty, in collaboration with Bandyopadhyay and A. Baveja has analyzed the stability of static solutions of spherically thin shell worm holes, when a slight perturbation is applied to them. The modified Chaplygin gas has been chosen as a candidate for exotic matter around the throat and different cases for such thin shell worm hole construction has been studied.

Moreover, Chakraborty, in collaboration with R. Biswas has studied black hole thermodynamics for various black hole solutions in modified Einstein gravity. They have considered Einstein-Maxwell-Gauss-Bonnet black hole solution with or without cosmological constant and black hole in Einstein-Gauss-Bonnet gravity with a Yang-Mills field. Behaviour of thermodynamic quantities have been analyzed, possibility of extremal black hole has been investigated and thermodynamic geometry has been presented. Finally, Hawking-Page phase transition has been examined.

Sushant G. Ghosh

Sushant Ghosh, in collaboration with Sanjay Jhingan, has considered a Lemaitre - Tolman - Bondi type spacetime in Einstein gravity with the Gauss-Bonnet combination of quadratic curvature terms, and obtained exact solution in closed form. It turns out that the presence of the coupling constant of the Gauss-Bonnet terms $\alpha > 0$ completely changes the causal structure of the singularities from the analogous general relativistic case. The gravitational collapse of inhomogeneous dust in the five-dimensional Gauss-Bonnet extended Einstein equations leads to formation of a massive, but weak, time-like singularit, which is forbidden in general relativity. Interestingly, this is a counter example to the three conjectures, namely, cosmic censorship conjectures, hoop conjecture and Seiferts conjecture.

Ghosh and Jhingan have also obtained solutions that are generalization to Einstein-Gauss-Bonnet gravity of the 5 dimensional quasi-spherical Szkeres like solutions in general relativity. It is found that the collapse proceeds in the same way as in the analogous spherical collapse, i.e., there exists a regular initial data such that the collapse proceeds to form naked singularities violating the cosmic censorship conjecture. The effect of Gauss-Bonnet quadratic curvature terms on the formation and locations of the apparent horizon has been s deduced.

Ghosh and Naresh K. Dadhich Dadhich have found an exact non-static spherically symmetric black hole solution of the higher dimensional Einstein-Yang-Mills (YM) equations for null dust with Yang-Mills. It is interesting to note that gravitational contribution of YM gauge charge for this ansatz is indeed opposite (attractive rather than repulsive) that of Maxwell charge. It turns out that the gravitational collapse of null dust with YM gauge charge admits strong curvature shell focusing naked singularities violating cosmic censorship.

However, there is significant shrinkage of the initial data space for a naked singularity of the HD-Vaidya collapse due to presence of YM gauge charge.

Sanjay Jhingan

Sanjay Jhingan has studied phenomenon of gravitational collapse and formation of singularities in the framework of higher order gravity theories, together with S. G. Ghosh. Among the higher curvature gravities, the most extensively studied theory is the so-called Einstein-Gauss-Bonnet (EGB) gravity. The EGB gravity is a special case of Lovelock's theory of gravitation, whose Lagrangian contains just the first three terms. The Gauss-Bonnet term yields non-trivial dynamics in dimensions greater than or equal to 5. It appears naturally in the low energy effective action of Heterotic sting theory. In this, the general solution, in a closed form, which is a kind of generalized LTB spacetime in the 5D EGB gravity with the energy momentum tensor of a dust is derived. The nature of singularities of such a spacetime hidden within a black hole, or whether it would be visible to outside observers, and the consequence of EGB on 5D-LTB collapse is also analyzed in detail. Moreover, a detailed analysis on apparent horizon and strength of singularity is developed.

N.G. Ibohal

N. G. Ibohal, C. H. Ishwarchandra and Jugindro Sing have proposed a new exact solution of Einsteins field equations. They have found that the spacetime geometry of the solution is nonasymptotic and conformally flat, whose energy-momentum tensor possesses a dark fluid (non-perfect fluid), with negative pressure and energy equation of state parameter. They have also found that the time-like vector of the matter distribution of the solution is expanding, shearing with acceleration. It is also found that, due to the negative pressure, the energy-momentum tensor of the solution violates the strong energy condition causing the repulsion of the gravitational field of the spacetime geometry. From these physical properties of the energy-momentum tensor, they have inferred that the spacetime metric as dark matter solution of the Einsteins field equations possessing dark fluid with negative pressure. They have also found an approximate size of the mass of dark matter as in Boussos length scale.

They have extended the above non-rotating solutions of Einsteins field equations to describe a rotating dark energy solutions. They have found that the rotating stationary solution is a non-asymptotic, Petrov type D spacetime, whose energy-momentum tensor admits a dark energy having negative pressure and energy equation of state parameter with minus sign. Further, the time-like vector fields of the matter distribution is expanding, shearing and rotating with acceleration. They have also analyzed the entropy and surface gravity for the horizon of the rotating dark energy solution.

Ibohal and Kapil have proposed a class of embedded solutions of Einsteins field equations describing non-rotating Reissner-Nordstrom-Vaidya and rotating Kerr-Newman-Vaidya black holes. The Reissner-Nordstrom-Vaidya is obtained by embedding Reissner-Nordstrom solution into non-rotating Vaidya. Similarly, they have also found the Kerr-Newman-Vaidya black holes, when Kerr-Newman embeds into the rotating Vaidya solution. The Reissner- Nordstrom-Vaidya solution is type D, whereas Kerr-Newman-Vaidya is algebraically special type II of Petrov classification of spacetime. These embedded solutions can be expressed in Kerr-Schild ansatze on different backgrounds. The energy momentum tensors for both non-rotating, as well as rotating embedded solutions satisfy the conservation equations, which show that they are solutions of Einstein's field equations. The surface gravity, area, temperature and entropy are also presented for each of the embedded black holes. It is observed that the area of the embedded black holes is greater than the sum of the areas of the individual ones. By considering the charge to be a function of radial coordinate, it is shown that there is a change in the masses of the variable charged black holes. If such radiation continues, the mass of the black holes will evaporate completely, thereby, forming instantaneous charged black holes and creating embedded negative mass naked singularities, describing the possible life style of radiating embedded black holes during their continuous radiation processes

V.C. Kuriakose

One of the greatest goals in theoretical physics of today is to realize a quantum version of gravity. Attempts are being made in the past to explain gravity in the framework of quantum field theory but without any success. Recently, a renormalizable theory of gravity in 3+1 dimensions was proposed by Horava, inspired from the Lifshitz theory in condensed matter physics, now known as Horava-Lifshitz (HL) theory. The theory is a potential candidate of quantum field theory of gravity. It assumes a Lifshitz-like anisotropic scaling between space and time at short distances, characterized by a dynamical critical exponent $z = 3$ and thus, breaking the Lorentz invariance. Stability of black holes in HL theory is a topic of interest in this area too. There are strong indirect evidences for the existence of black holes, and if the black holes are found to be unstable in the new theory it may question the reliability of the theory itself. Nijo and V.C. Kuriakose have investigated the evolution of gravitational perturbations in black hole spacetime in HL theory and associated quasinormal modes (QNMs) are evaluated. The negative imaginary part of QNMs show that the perturbation will decay in time and hence one can conclude that black holes are stable against small perturbations in the spacetime. The present calculations show that the gravitational QNMs are long lived in Horava theory compared with the Schwarzschild black hole.

K.K. Nandi

K. K. Nandi has been working on the features of galactic haloes, phase shift caused by the Chern-Simons term and energetics in gravastar and wormholes. Other works include the suggestion of a new effect of gravitational time advancement.

Farook Rahaman

F. Rahaman, together with K.K. Nandi, A.I. Filippov, Saibal Ray, A.A. Usmani, M. Kalam and A. DeBenedictis, has investigated several aspects of the imprint of the 5-dimensional bulk Weyl radiation within a recently proposed model solutions. It has been shown that the solution has a number of physically interesting properties. The constraints on the model imposed by combined measurements of rotation curve and lensing have been discussed. A brief comparison with a well known scalar field model is also given. Rahaman, together with Saibal Ray, M. Kalam and M. Sarker, has performed a survey whether higher dimensional Schwarzschild spacetime is compatible with some of the solar system phenomena. Together with M. Jamil, he has investigated a cosmological model in which three fluids interact with each other, involving certain coupling parameters and energy exchange rates. The motivation of the problem stems from the puzzling triple coincidence problem, which naively asks why the cosmic energy densities of matter, radiation and dark energy are almost of the same order of magnitude at the present time. In their model, they have determined the conditions under which, triple interacting fluids will cross the phantom divide. Together with Jamil and Kalam, Rahaman has investigated the spacetime of anisotropic stars admitting conformal motion. Together with Jamil, A. Ghosh and K. Chakraborty, he has presented an algorithm to generate various black hole solutions in general relativity and alternative theories of gravity. By applying Darmois-Israel formalism, in collaboration with Kalam and K. A. Rahman, he has also established a new class of thin shell wormhole in the context of global monopole resulting from the breaking of a global O(3) symmetry.

Biplab Raychaudhuri

A study of perturbation of black holes in (2+1) dimension, static charged dilaton gravity has been done along with Kshounish Guha. Gravity in lower dimensions has attracted the attention of the physicists in recent years. The study of the Einstein's theory of gravity in (2+1) dimensions has been widely recognized as a useful theoretical laboratory to explore the foundations of classical and quantum gravity. The lower dimensional setting provides a significant amount of technical simplification of gravitational field equations. The conceptual issues that are often obscured in the more complicated (3+1) dimensional theory, are brought into sharper focus in (2+1) dimensional theory. Initially, it was widely believed that (2+1) dimensional gravity will not admit a black hole solution. The Banados-Teitelboim-Zanelli (BTZ) black hole locally has asymptotically anti-de Sitter structure. BTZ black hole enjoys many properties of its counterpart in higher dimensions. Recent research has indicated that there are a wide class of (2+1) dimensional black holes. These black holes arise as exact solutions to Einstein-Maxwell dilaton theory in (2+1) dimensions. Chan and Mann in 1994 obtained an interesting oneparameter family of static charged nonasymptotically anti-de Sitter black hole solutions in (2+1) dimensions. This black hole can be compared to charged dilaton black holes in (3+1) dimensions constructed by Gibbons and Madea (1988) and, Garfinkle, Horowitz and Strominger (1991). This black hole solution depends on a parameter N. Biplab Raychaudhuri studied the scalar perturbation of this black hole. Presently, he has been also studying the conditions of the superradiance, which should depend on different parameters.

It has recently been observed that cosmological constant, which is claimed to play a vital role in the acceleration of universe, may have its origin at the time of the symmetry breaking stage during the phase transition at the time of evolution of early universe. Based on this work, an essay has been submitted to Gravity Research Foundation.

M. Sivakumar

There are attempts to investigate gauge theory, arising from matrix models which can lead to emergent spacetime and emergent gravity. A matrix model has been studied by M. Sivakumar and H.S. Yang to show that constant curvature spacetime emerge as vacuum geometry. Fluctuations of geometry were shown to be related to gauge field fluctuations of a NC spacetime. Sivakumar and E. Harikumar have studied Dirac equation, associated with kappa deformed spacetime. Hydrogen atom spectrum has been studied and qualitative signatures, which distinguish from other quantum gravity studies have been made. Also, bounds on the deformation parameter from the spectrum have been found.

Studies on geometric finiteness and holography have been extended to warped black hole. Quasinormal modes have been calculated using this approach. This has been done by Sivakumar, Kumar Gupta, Harikumar and Siddhartha Sen.

A.A. Usmani

A new type of thin-shell wormhole has been constructed by applying the cut-and-paste technique to two copies of a charged black hole in generalized dilaton-axion gravity, which was inspired by low-energy string theory. Various aspects of this thin-shell wormhole, such as the amount of exotic matter required, the attractive or repulsive nature of the wormhole, and a possible equation of state for the thin shell and its stability to linearized spherically symmetric perturbations have been analyzed and discussed.

Cosmology and Structure Formation

N. Iqbal

N. Iqbal, along with M. S. Khan has studied phase transitions occurring in gravitational clustering of galaxies on the basis of thermodynamic theory. This is because, the fluctuations in number and energy of the particles are constantly probing the possibility of a phase transition. Calculation of various moments of the fluctuation thermodynamic extensive parameters like, the number and energy fluctuations has been performed. The correlated fluctuations have shown some interesting results. For weak correlations, their ensemble average is positive, indicating that a region of density enhancement typically coincides with a region of positive total energy. Its perturbed kinetic energy exceeds its perturbed potential energy. Similarly, an underdense region has negative total energy since, it has preferentially lost the kinetic energy of the particles that have fled. For larger correlations, the overdense regions typically have negative total energy, and underdense regions have positive total energy. The critical value at which this switch occurs is the critical temperature $T = T_C$, whose value has been calculated analytically.

Deepak Jain

The nature of the dark sector (dark matter and dark energy) of the universe and their role in the evolution of the structure formation is completely an open question at present. Motivated by recent developments in the cosmology, the possibility of interaction among the dark components has been studied extensively in the literature. This scenario gives rise to coupled quintessence model, which can explain the present cosmic acceleration, as well as the other observational results also.

Deepak Jain, along with Abha Dev, Jailson S. Alcaniz and R. S. Goncalves has investigated the compatibility of this model with the recent galaxy clusters x- ray gas mass fraction data. They put the bound on the interaction parameter, which signifies the coupling between the dark matter and dark energy. This result is consistent with the limit obtained by other cosmological tests.

They have been also exploring other observational tools, such as lookback time redshift method and cosmological redshift drift test to constrain the various dark energy models.

Sanjay Jhingan

Using supernovae as standard candles is a popular method of constraining the properties of dark energy. Though this method is very simple and useful in constraining the various dark energy models, at present the luminosity distance measurements suffer from many systematical uncertainties like extinction by dust, gravitational lensing, etc. On the other hand, measuring the expansion history from growth of matter perturbations also has its limitations. It requires prior information of exact value of matter density, initial conditions, cosmological model, etc. So, the question arises, "is there any probe which is simple, which depends on fewer priors and assumptions?" The possible probe is "Cosmological Redshift Drift" (CRD) test, which maps the expansion history of the universe directly (first proposed by Loeb). The aim of this work is to employ CRD test to constrain various accelerating models both within the framework of general theory of relativity (GTR) and beyond GTR. Sanjay Jhingan and Deepak Jain have used simulated data points for redshift-drift experiment generated by Monte-Carlo simulations, with the assumption of standard cosmological model Cold Dark Matter (CDM) as reference. They have put constraints on the quintessence models (based on scalar field potentials) like inverse power law and exponential potentials. The dark energy parametrization, which has a variable equation of state was also investigated. Also, bounds are proposed on the f(R) gravity models, i.e., Starobinsky model, using the CRD.

Minu Joy

Minu Joy has been studying the primordial non-Gaussianity. In the context of standard single field inflation, in which the scalar field is slowly rolling down the potential, one generically expects that the non-Gaussianity parameter is small; of the order of the so called slow-roll parameters. But the recent CMB observations suggest a much higher value. Then, it is interesting to study how can such a large non-Gaussianity be generated? A novel inflationary model, which can explain the small wiggles or local spikes superimposed on an approximately scale invariant spectrum has been proposed by Minu Joy, V. Sahni and A.A. Starobinsky. They have considered the case, where the inflaton potential experiences a sudden small change in the second derivative (the effective mass of the inflaton), and showed that the resulting power spectrum has certain small oscillations superimposed on the almost flat spectrum and the spectral index has a step. Joy has been interested in studying the non-Gaussianity predicted by this model. Since the feature in the inflationary potential leads to small corrections to slow-roll, one can estimate the non-

Gaussianity. This can be done by expanding the action to third order in the comoving gauge. Joy and her collaborators have computed the 3-point function of the curvature perturbation for this inflationary model and showed that there would be three more terms, which contribute at order of the square of slow-roll parameters. These terms affect scales that exit Hubble horizon around the time the field crosses the feature in the potential. They have computed these extra terms and studied the shape and scale dependence of the 3-point function.

T.R. Seshadri

T.R. Seshadri, in collaboration with Pranjal Trivedi and K. Subramanian,has been investigating the non-Gaussian signals from the Cosmic Microwave Background Radiation (CMBR). In particular, bispectrum in the CMBR expected from the passive modes of the Primordial Magnetic Fields (PMF) has been studied. The aim is to put bounds on such magnetic fields. The significance of this study is that unlike density perturbations, such magnetic fields can produce non-Gaussian signals even at the lowest order.

In collaboration with Shruti Thakur and Anjan Ananda Sen, Seshadri has been working on modified gravity models in which, action has terms higher order in R. Models have been constructed, which have a matter dominated type behaviour followed by a cosmological constant type behaviour in recent times.

In collaboration with Isha Pahwa and D. Choudhury, late time accelerated expansion of the universe arising out of higher dimensional cosmological models has been investigated by Seshadri. Preliminary results show that such a possibility exists. Investigations are being done on how this depends on the number of extra dimensions.

Seshadri, in collaboration with Kumar Atmjeet and L. Sriramkumar has worked on the generation of primordial magnetic fields in the early universe. A scalar field assisted break down of conformal invariance is being investigated.

Galaxies and Quasars

Pushpa Khare

Pushpa Khare, along with her collaborators, has studied a large sample of damped and sub-damped Lyman α (DLA and sub-DLA) systems to determine the $N_{\mathrm{H\,I}}$ weighted mean metallicity of Fe and Zn in these systems. For both elements, the $N_{\mathrm{H\,I}}$ weighted mean metallicity is higher and shows faster evolution in sub-DLAs than the classical DLA systems. Photoionization models show that the ionization corrections to the abundances in sub-DLAs are in general small, even though, the fraction of ionized hydrogen can be up to $\sim$ 90%. Study of the composite, absorber rest frame spectra shows that the average abundance pattern of the sub-DLA systems is similar to the gas in the halo of the Milky Way, with an offset of $\sim$ 0.3 dex in the overall metallicity. Both DLAs and sub-DLAs show similar characteristics in their relative abundances patterns, although, the DLAs have smaller $<$[Mn/Zn]$>$, as well as higher $<$[Ti/Zn]$>$ and $<$[Cr/Zn]$>$. The sub-DLA systems at $z < 1.5$ contain a co-moving density of metals $\sim$ (3.5 - 15.8)$\times 10^5 M_\odot$ Mpc^{-3}, at least twice that in the DLA systems.

V.C. Kuriakose

The availability of several thousands of quasi-stellar object (QSO) spectra in the Sloan Digital Sky Survey (SDSS) data base has allowed astronomers to find various interesting and peculiar active galactic nuclei (AGN). In particular, the discovery of unresolved point sources with two sets of emission lines that are powered by AGN-like continuum sources [SDSS J092712+294344 at z = 0.713, SDSS J153636+044127 at z = 0.38 and SDSS J105041+345631 at z = 0.272] has opened up possibilities to study recoiling black holes and/or binary inspiralling supermassive black holes. M. Vivek and V.C. Kuriakose, in collaboration with R. Srianand and V. Mohan, have carried out long-slit spectroscopic observations of SDSS J092712+294344 using the 2m telescope in IUCAA Girawali Observatory, India. This AGNs like source is known to feature three sets of emission lines at $z_{em} = 0.6972$, 0.7020 and 0.7128. Different scenarios, such as a recoiling black hole after asymmetric emission of gravitational waves, binary black holes and possible merging systems are proposed for this object. Based on the observations, they have concluded that the binary black hole model is most unlikely. The spatial extent and the sizes are consistent with both black hole recoil and merging scenarios.

Shantanu Rastogi

Active Galactic Nuclei (AGNs) show large rapid variability in x-rays, that are produced in the innermost region of the accretion disk. The study of AGNs in x-ray offers potential to understand the nature of the central supermassive black hole. Using satellite observations, the variability can be quantified by Fourier analysis of the light curve to determine power spectral densities. Most of the AGNs are characterised by a power spectrum, approximated by a steep power law at high frequencies breaking to a flatter index below some break frequency. A three dimensional relationship exists amongst the break time scale, bolometric luminosity and the mass of the black hole.
Shantanu Rastogi, along with Ranjeev Misra and Shruti Tripathi has undertaken a systematic study of a sample of AGNs, where the black hole mass is known accurately by Reverberation Mapping technique. There are 98 multiple XMM-Newton satellite observations of the sample objects. The motivation is to study the relation of black hole mass with variability and luminosity. The study involves computation of power spectra and photon spectra for all 98 observations in different energy bands, developing techniques to reliably estimate time lags in different energy bands using cross correlation and cross spectra methods and using the optical/UV data to give multiwavelength spectrum.

Sandeep Sahijpal

Recently, Sandeep Sahijpal has developed a numerical code for the galactic chemical evolution of isotopes from 1H to 68Zn. This work considers the evolution of our galaxy since its formation after the big-bang. He has incorporated the updated prescription of the star formation rate, the stellar initial mass function, the stellar nucleosynthetic yields for different stellar masses and metallicities. The various stellar sources include novae, low and intermediate mass asymptotic giant branch (AGB) stars, supernovae (SN) type Ia, Ib/c, II, and Wolf-Rayet stars. He has been able to generate the temporal dependence of all the isotopes.

Compact Objects and X-ray Binaries

Tanuka Chattopadhyay

In collaboration with G. Jogesh Babu, Asis Chattopadhyay and Saptarshi Mondal, Tanuka Chattopadhyay has studied the proper interpretation of horizontal branch (HB) morphology, which is crucial for understanding of the formation history of stellar population. For the above study, multivariate analysis has been used (principal component analysis) for the selection of appropriate HB morphology parameter, which, in the present case is the logarithm of effective temperature extent of the HB (log T eff HB). Then this parameter is expressed in terms of the most significant observed independent parameters of galactic globular clusters (GGCs) separately for coherent groups, obtained in a previous work, through a stepwise multiple regression technique. It is found that, metallicity ([Fe/H]), central surface brightness and core radius are the significant parameters to explain most of the variations in HB morphology for GGC belonging to the bulge/disk while metallicity ([Fe/H]) and absolute magnitude are responsible for GGC belonging to the inner halo. The robustness is tested by taking 1000 bootstrap samples. A cluster analysis is performed for the red giant branch stars of the GGC belonging to galactic inner halo. A multi-episodic star formation is preferred for RGB stars of GGC belonging to this group. It supports the asymptotic giant branch (AGB) model in three episodes instead of two as suggested by Carretta, et al. for halo GGC, while AGB model is suggested to be revisited for bulge/disk GGC.

S.N.A. Jaaffrey

S.N.A. Jaaffrey and his group have been actively engaged in multi wavelength spectroscopic studies of the GRBs, x-ray Binaries, the sun and secondary x-ray environment in the lower atmosphere of the earth. His group has studied some of the specific x-ray binaries EXO2030+375, 4U0115+634 and found milli second QPOs. They have detected 3 QPOs for the 4U0115+634, which is quite surprising in recent burst of 2008. Also, in GRB050525, they have found negative lag delays after rigorous analysis.

M.K. Patil

M.K. Patil, in collaboration with S.K. Pandey and A.K. Kembhavi, using the Chandra archival x-ray data on a sample of early-type galaxies, has detected more than 1000 discrete x-ray sources. 82% of which are lying within the D_{25} region. Spectra of all the resolved point sources within D_{25} were fitted using XSPEC software and were best-fitted with powerlaw model. The x-ray luminosity function (XLF) of each galaxy is consistent with a powerlaw with negative logarithmic differential slope. The composite XLF is well fitted by a power law with a break. The break is close to the Eddington limit for a 1.4 solar mass neutron star and can be explained in terms of the main evolutionary relations for the rate of mass transfer onto a compact companion. To investigate the spectral properties of point source, they have produced x-ray colour-colour plots for individual point sources in each galaxy and have found that most of the detected sources are LMXBs and very few are the super-soft sources with white dwarf as the accreting component.

Astrostatistics

Asis Kumar Chattopadhyay

Asis Kumar Chattopadhyay has carried out an objective classification of the globular clusters (GCs) of NGC 5128 by using a model-based approach of cluster analysis. The set of observable parameters includes structural parameters, spectroscopically determined Lick indices and radial velocities from the literature. The optimum set of parameters for this type of analysis is selected through a modified technique of principal component analysis, which differs from the classical one in the sense that it takes into consideration the effects of outliers present in the data. Then a mixture model based approach has been used to classify the GCs into groups. The efficiency of the techniques used is tested through the comparison of the misclassification probabilities with those obtained using the K-means clustering technique. On the basis of the above classification scheme, three coherent groups of GCs have been found. The properties of these three groups have been studied to identify the possible origins.

Comets, Meteors and Solar System

H.S. Das

H.S. Das has studied the light scattering properties of comet Huakutake and comet Halley using superposition T-matrix code and try to analyze the observed polarization properties of the two comets. The observed linear polarization data of comet Hyakutake are studied at wavelengths $\lambda = 0.365\mu m$, $0.485\mu m$ and $0.684\mu m$ through simulations using Ballistic Particle-Cluster Aggregate (BPCA) and Ballistic Cluster-Cluster Aggregate (BCCA) of 128 spherical monomers. It is found that the size parameter of the monomer, $x \sim$ 1.561.70, turned out to be the most suitable, which provides the best fits to the observed dust scattering properties at three wavelengths: $\lambda = 0.365\mu m$, $0.485\mu m$ and $0.684\mu m$. Now, using superposition T-matrix code and the powerlaw size distribution, $n(r) \sim r^3$, the bestfitting values of complex refractive indices have been calculated for the observed polarization data at the above three wavelengths. The refractive indices derived from the present analysis correspond to a mixture of both silicates and organics, are in good agreement with the in situ measurement of comets by different spacecraft.

The in situ measurements of comet Halley and the Stardust returned samples of comet Wild 2 showed the presence of a mixture of silicates and organic refractory in cometary dust. Das has proposed a model, which considers cometary dust as a mixture of aggregates and compact particles. He has considered the aggregates as ballistic cluster-cluster aggregate (BCCA) and ballistic agglomeration with one migration (BAM1) aggregate and compact particles as spheroidal particles with some size distribution. For modeling comet 1P/ Halley, the power-law size distribution $n(a) \sim a^{-2.6}$, obtained from re-analysis of the Giotto spacecraft data, is taken. Using T-matrix code for polydisperse spheroids and superposition T-matrix code for aggregates, the average simulated polarization curves have been generated, which can best fit to the observed polarization data at the three wavelengths $\lambda = 0.365\mu m$, $0.485\mu m$ and $0.684\mu m$. The best fitting complex refractive indices coming out from the present analysis correspond to a mixture of both silicates and organics, which are in good agreement with the *in situ* measurement of comet 1P/Halley by different spacecraft. The model successfully reproduces the positive, part as well as the negative branch of the polarization at the above three wavelengths.

N. Iqbal

N. Iqbal. along with T. Masood, A. Ahmad and M.N. Vahia has studied the meteor fall of 2009 in Northern India. A sample of Akhnoor meteor crater, which fell on January 2, 2009 in Jammu District, Jammu and Kashmir, India, has been analyzed for elemental composition by spectroscopic techniques. Concentrations of 17 major, minor and trace elements were determined. The authenticity of the meteorite sample was established by comparing its composition with those of standard meteorites/chondrite. The classification of the sample has been made by comparing the abundances and concentration ratios of elements with other known meteorites. The plot obtained from the analysis between the concentrations of different elements found in the Akhnoor meteor crater and their average concentration shows high abundance of some trace elements indicating that the sample is not of terrestrial origin, but shows resemblance with an extra terrestrial origin. Other plots between the concentration of different elements present in the Akhnoor meteor crater and the average concentration of different elements for a stony meteorite completely merge with each other confirming that the meteorite is a chondrite and not an iron meteorite.

S.N.A. Jaaffrey

S.N.A. Jaaffrey and his group have also investigated evidences for magneto convection, flashes and running penumral waves in umbral dots present in sun spots using high resolution spectrophotometry data from Hinode.

Moreover, his group has also started pursuant research on secondary x-ray environment in the lower atmosphere of the earth, which is produced by high energy primary cosmic radiation impact. This kind of research has been the new tool in the search of pollutants brought up by the monsoon, anthropogenic activities and meteoric showers.

Nagendra Kumar

Nagendra Kumar, in collaboration with Anil Kumar and Pradeep Kumar, has studied the effect of complex magnetic field on the solar p-modes by using a model in which the convection zone of the sun is represented by a gravitationally stratified fluid having the linear temperature profile with uniform horizontal flow. Chromosphere is taken as an isothermal medium permeated by complex magnetic field. An exact dispersion relation is obtained and is solved analytically. Investigation shows that the high degree modes are affected by complex magnetic field. The influence of flow is much more than the magnetic field on frequency shift. Waves and oscillatory activities are observed within the solar corona with modern imaging and spectral instruments. These oscillations were interpreted as signatures of slow magneto-acoustic waves excited impulsively in the loops. Nagendra Kumar along with his students explored the effect of equilibrium flow on the propagation and dissipation of slow magneto-acoustic waves in the solar coronal plasma permeated by uniform magnetic field. This study has been aimed to improve current theories of solar coronal heating based on the dissipation of MHD waves. Damping of slow waves in the coronal plasma, taking into account viscosity and thermal conductivity as dissipative processes, has been studied. On solving the dispersion relation that arises from the linearized one-dimensional MHD equations, it is found that the presence of plasma flow influences the characteristics of wave propagation and dissipation. The time damping of slow waves exhibits varying behaviour depending upon the physical parameters of the loop. The wave energy flux associated with slow magnetoacoustic waves turns out to be of the order of 10^6 erg cm^{-2} s^{-1}, which is high enough to replace the energy lost through optically thin coronal emission and the thermal conduction below to the transition region. Wave periods for slow-mode waves are calculated and are compared with the observed oscillation periods of loops.

Saibal Ray

Saibal Ray and his group have performed a survey, whether higher dimensional Schwarzschild space-time is compatible with some of the solar system phenomena. As a test, four well known solar system effects, viz., (1) Perihelion shift, (2) Bending of light, (3) Gravitational redshift, and (4) Gravitational time delay have been examined. It is shown, under a N-dimensional solutions of Schwarzschild type very narrow class of metrics, that the results related to all these physical phenomena are mostly incompatible with the higher dimensional version of general relativity. We compare all these restricted results with the available data in the literature (Rahaman, et al. Int. J. Theor. Phys. 48 (2009) 3124). In continuation to the investigation of flat rotational curves of the galaxies under the framework of brane-world models, several aspects of the 4d, imprint of the 5D bulk Weyl radiation have been investigated within a recently proposed model solution. It is shown that the solution has a number of physically interesting properties. The constraints on the model imposed by combined measurements of rotation curve and lensing are discussed. A brief comparison with a well-known scalar field model is also given.

Sandeep Sahijpal

S. Sahijpal has been working on the formation and the early evolution of the solar system. Based on the survey of active star forming regions, he has proposed a novel scenario regarding the astrophysical environment associated with the origin of our solar system. He has hypothesized that the formation of the solar system could have occurred almost contemporaneously with the formation of a massive star within a single stellar cluster. As the massive star eventually exploded as supernova Ib/c subsequent to Wolf-Rayet stages, the short-lived nuclides were probably injected into the solar proto-planetary disc. The dynamically evolving stellar cluster eventually dispersed within the initial 10 million years prior to the major planetary formation episodes.

Pranjal Trivedi

In collaboration with Sumant Bhushan and others, Pranjal Trivedi and their solar eclipse research group have been able to record shadow bands during the total solar eclipse, July 22, 2009, from Mohaniya, Bihar, India. This elusive phenomenon is fleetingly visible on the ground as a rapidly moving pattern of faint low-contrast light and dark bands just before and after a total solar eclipse. The band visibility and characteristics are dependent on the state of the atmosphere and the local circumstances of the eclipse. According to Codonas theory (1986), shadow bands are formed by the scintillation of light from the (eclipsed) thin solar crescent by a turbulent atmosphere. The video recording made by the group is the only such shadow bands recording reported for this eclipse over India and China. The bands are clearly visible at both second and third contacts at the expected orientation. The band speed, band separation, as well as the time series power spectra have been calculated and detailed analysis has been in progress. The groups observations of this rare phenomenon present an opportunity to test Codonas theory of shadow band formation and give information on atmospheric conditions at an eclipse.

Paniveni Udayashankar

Paniveni Udayashankar has aimed at the study of the morphological and dynamical properties of supergranulation, which are the large convective features on the Solar surface with a view to explore its possible turbulent origin. It focusses on how the size, lifetime, the horizontal flow field and the fractal structure, of supergranules are related to each other. Remarkably, the relationship between horizontal flow velocity and cell size very closely follows Kolmogorovs law of turbulence. Relationship between horizontal flow velocity and cell lifetime also supports turbulent convective model. It is further corroborated by the study of the fractal structure which sheds light on the complexity of supergranular cell boundaries. A variation of fractal dimension with the solar cycle, which is an important observation is being explored currently; whether it is due to a variation of the dynamo process during the cycle or to surface effects affecting the decay of active regions is still an open question. Supergranules play a key role in the transport and dispersal of magnetic fields as it is an important step in our quest to understand the solar cycle. Understanding the dynamics of supergranulation in the convective zone is important because the magnetic irregularities that convection produces such as sunspots can affect climate on earth.

Observational Astronomy

S. K. Pandey

The programmeof studying faint outermost region of the galaxies from the Large Format Camera (LFC) field has been continued during the year. A sample of 180 early-type galaxies (E/SO) have been chosen from LFC field SDSS 1208 for isophotal shape study to faint outer regions. Redshift for 72 galaxies of AAT observations were measured. Isophotal shape parameters at four different radial bins along the semi major axis of a galaxy were derived ,instead of assigning a single global characteristic value of the parameter for the galaxy to consider the radial variation of the parameters, which has not been done before. Possible correlation of isophotal shape parameters with other global properties of galaxies were investigated including spectral properties at nuclear region, and inspected whether the correlations change along the radius. Results were compared with the properties of isophotal shapes of merger remnants reported in the literature, obtained from N-body simulations. A paper entitled "Isophotal shapes of early-type galaxies to very faint isophotal levels" reporting the findings and will be submitted soon for publication. This is a collaborative research programme involving Laxmikant Chaware, A. K. Kembhavi, Russell Cannon, Ashish Mahabal, and S. K. Pandey, and constitutes the thesis work of Chaware.

As a part of an ongoing collaborative research programme with A. K. Kembhavi and other colleagues on multiwavelength photometric study of dusty early-type galaxies, the process of obtaining good quality deep images in BVRI broad bands, as well as in narrow H-alpha band was continued during the year. The 2 m telescope at IGO was used to obtain deep imaging in H-alpha band for 7 early-type galaxies during October 2009, January and March 2010 observing runs. Detailed analysis of dust properties has been performed along with the study of presence of ionized gas in early type galaxies. The work constitutes the doctoral work of Samridhi Kulkarni.

Madhav K. Patil

M.K. Patil, in collaboration with S.K. Pandey and A.K. Kembhavi, has carried out in-depth, detailed analysis of morphological and spectral properties of hot gas in about 50 nearby early-type galaxies selected from different environment. For this purpose, they have used the high resolution x-ray images available in the archive of Chandra X-ray Observatory. This analysis has enabled them to derive the diffuse emission maps of the target galaxies and also to disentangle the contribution of low mass x-ray binary sources (LMXBs) to the observed x-ray luminosity of the host galaxy. Fits to the surface brightness profiles and spectral fit of the hot gas alone resulted in to the determination of half light radius (Rx), gas temperature (Tx) and corresponding surface brightness (Ix), which in turn helped to examine the feasibility of x-ray gas fundamental plane of the early-type galaxies. They have found that the temperature and x-ray luminosity of these galaxies to range between $0.36-0.84$ keV and $1.39\times 10^{39} - 1.72 \times 10^{42}$ erg s^{-1}, respectively. All resolved sources in different galaxies provided a clear evidence for hard emission component, which has been parameterized by powerlaw model with photon indices in the range $\Gamma \approx 1.422.32$ and intrinsic cumulative luminosity $3.8 \times 10^{39} 5.210^{40}$ ergs^{-1}. With an objective of studying association of the multiple phases of ISM in early type galaxies, they have acquired CCD imaging data on the target galaxies in optical broad bands (BVRI) and narrow band (H-alpha) using the observing facilities available at IUCAA Girawali Observatory, during December 2007 to January 2010. From the analysis, they have derived colour index maps, extinction maps, as well as H-alpha emission maps of the target galaxies. This study has revealed that the x-ray emission morphology of the galaxies closely resembles with that of dust, as well as H-alpha emission in some of the galaxies implying that they have common origin. Further, they have observed that the contribution of x-ray emission from LMXBs to the total x-ray luminosity of dust lane galaxies is more compared to those in the normal galaxies. They have also studied the correlations between near-IR, optical, as well as x-ray emission from these galaxies.

Ravikumar C.D.

Ravikumar C D has been currently involved in the multi-wavelength analysis of Ultra-Luminous X-ray (ULX) sources in galaxies in collaboration with Ranjeev Misra, Swara Ravindra Nath, Gulab Dewangan and Ajit Kembhavi. The X-ray brightness of these sources are next to only the active galactic nuclei. Though the exact nature of ULXs is not clearly understood, it is proposed to be powered by the existence of intermediate mass blackholes (IMBHs, blackholes with 100 to a few thousand solar mass). In the ongoing research project funded by ISRO, K. Jeena and V. Jithesh have studied the optical counter parts of x-ray sources in a set of 24 elliptical galaxies, using Chandra/HST observations. Identifying x-ray sources without optical counter parts, we estimate the upper limit to the masses of underlying blackholes and find that they belong to the class of IMBHs. U. Preetha has been carrying out detailed morphological analysis of these galaxies using full two-dimensional bulge disk decomposition algortithm.

Archaeoastronomy

N. Iqbal

N. Iqbal, along with T. Masood, A. Ahmad and M. N. Vahia have used various approaches of archaeoastronomy to identify some past astronomical records like ancient meteor impact, supernova, solar eclipses and many others. The supernovae recorded and studied seems to agree most with the sky map chart. The pre-historic meteor event seems to be in accordance with the meteor event of January 17, 2004, as observed by the Swedish Infrasound Network.

Radio Astronomy

Joe Jacob

Joe Jacob, in collaboration with Joydeep Bagchi, has extended his studies of galaxy clusters into the optical band in a bid to correlate it with the radio studies. He has taken photometric and spectroscopic observation of the mini radio halo source MRC 0116+111. The U, V, B, R band photometry and spectroscopy employing the IFOSC 7 and IFOSC 8 of the observatory had been carried out utilizing the three night observations during the January 7 - 9, 2010. The data obtained is being analysed for scientific results. This study was proposed in order to find the possible connection between the cooling flows and the star formation rate in the cD galaxy under study. It is expected that the cooling flows will be substantially disrupted by the feedback process in AGNs and this will have its tell-tale influence on the star formation rate of the galaxy. The strategy is to study the star formation rate of analogous cD galaxies with and without associated AGNs from the data available with the virtual observatories, to get some standard correlations and to find where the optical observations of the galaxy under study will fit. It is expected that the study will reveal a connection between SFR and the feedback process thereby shedding more light into the formation of radio mini-halos.

Besides these research activities, he has been actively spearheading the astronomy popularization activities in the district of Idukki in Kerala. He and his colleague Ravi K. Pillai have teamed up with the governmental organization, Kudumbashree, and initiated the popularization project by name Sashtragramam (meaning science village) among the less privileged children of the remote villages of the district, as a part of the IYA activities. The project, which was carried out in three phases, starting from the interaction and presentations in the village level, progressed with talent meets conducted at block levels and culminated in a district level two day residential astronomy camp for children with a skywatch programme. Eighty-seven children selected according to merit from the various villages of the district participated in the camp, of which, 20 were selected and given an opportunity to visit the planetarium at Thiruvananthapuram. They also got the golden opportunity to visit IUCAA and to interact with the people and facilities there during April 7-10, 2010. Besides, with the support from his colleagues and the IRC, Kochi, he has conducted many skywatch programmes in various schools in the district and a sensitization programme for the school teachers during the year.

B.C. Paul

P.K. Chattopadhyay and B.C. Paul have examined a class of relativistic solutions of compact stars in hydrostatic equilibrium in higher dimensional framework which has been obtained assuming a pseudo-spheroidal geometry (Vaidya-Tikekar metric) for the spacetime. The spacetime geometry is assumed to be a (D-1) pseudo-spheroid immersed in a D-dimensional Euclidean space. The spheroidicity parameter λ plays an important role in determining the equation of state of the matter content and the maximum radius of such stars. The core density of compact objects is approximately proportional to the square of the spacetime dimensions (D), i.e., core of the star is denser in higher dimensions than that in convensional four dimensions. The central density of a compact star is also found to depend on the parameter λ. A physically interesting solution is obtained satisfying the acoustic condition when λ lies in the range $\lambda > (D+1)/(D-3)$ for the spacetime dimensions ranging from $D = 4$ to $D = 8$ and $(D+1)/(D-3 < \lambda < (D^2-4D+3)(D^2-8D-1)$ for spacetime dimensions $D \geq 9$. The non-negativity of energy density ρ constrains the parameter with a lower limit $\lambda > 1$. They have noted that for a super dense compact object the number of spacetime dimensions cannot be taken infinitely large, which is a different observation from that of the braneworld model.

Considering a Lagrangian density, which is a polynomial function of scalar curvature (R) in the Einstein-Hilbert action they have obtained cosmological models. The field equation obtained from the modified action corresponding to a Robertson-Walker metric is highly non-linear and not simple enough to obtain analytic solution. Consequently, B.C. Paul, P.S. Debnath and S. Ghosh have adopted a numerical technique to study the evolution of the FRW universe. A number of evolutionary phases of the universe, including the present accelerating phase are found to exist in the higher derivative theories of gravity. They have studied modified theory of gravity as a toy model to explore the past, the present and predict the future evolution. It is found that all the models analyzed here can reproduce the current accelerating phase of expansion of the universe. They have noted that the duration of the present accelerating phase is found to depend on the coupling constants of the gravitational action. The physical importance of the coupling parameters considered in the action are also discussed.

(III) IUCAA-NCRA GRADUATE SCHOOL

Seven IUCAA Research Scholars, Susmita Chakravorty (Guide: Ajit Kembhavi), H.K. Das (Guide: Ranjan Gupta), Abhishek Rawat (Guide: Ajit Kembhavi), Saumyadip Samui (Guide: K. Subramanian; Co-Guide: R. Srianand), Sudipta Sarkar (Guide: T. Padmanabhan), Arman Shafieloo (Guide: Varun Sahni), Sharanya Sur (Guide: K. Subramanian), have defended their Ph.D. theses submitted to the University of Pune during the year of this report. The abstracts of the same are given below:

Physics of Radiation from AGN

Susmita Chakravorty

Signatures of warm absorbers are seen in soft x-ray spectra of about half of all Seyfert 1 galaxies observed and in some quasars and blazars. The properties of warm absorbers are important for studying the structure of AGN, feedback to the intergalactic medium and possibly the physics of accretion into the black holes powering the AGN. One way to study these systems is to investigate the effect of various factors on the warm absorber conveniently using the thermal equilibrium curve or the stability curve which is a phase space diagram of temperature (T) against the ratio of ionization parameter ($\xi = L/nR^2$) to T. The aim is to investigate if the warm gas is in thermal equilibrium and if so, does it have multiple stable phases in pressure equilibrium with each other. It is long known that the range of physical parameters over which the stability curves show the existence of warm absorbers is rather limited and the range over which a multiphase absorber is possible is even smaller. However, high resolution spectroscopy in recent times, using the x-ray observatories XMM-Newton and Chandra, suggests that a significant fraction of the AGN have warm absorber in multiple phases. Some of these are still under debate.

The shape of the stability curve is determined by the physical factors like the spectrum of the ionizing continuum and the chemical composition of the gas. Although work has been done on the stability curves for warm absorbers, there does not exist a detailed and systematic study of the properties of the warm absorber as a function of the shape of the ionizing continuum and the gas abundance.

Simulations of the stability curve are affected by the knowledge (or rather the lack of it) of the atomic data base used in the calculations. We find that the stability curves obtained using recently derived dielectronic recombination rates, give significantly different results, especially in the regions corresponding to warm absorbers, from earlier calculations performed for similar physical parameters, but using older atomic data. Using the current rates we find a larger probability of having thermally stable warm absorber at 10^5 K than previous predictions and also a greater possibility for a multiphase nature. In particular, we find that the results obtained with the current dielectronic recombination rate coefficients are more reliable because, the warm absorber models along the stability curve have computed coefficient values, whereas the previous calculations relied on guessed averages for the same due to lack of available data.

We use the thermal equilibrium curve to study the influence of the shape of the ionizing continuum, and the density and chemical composition of the absorbing gas on the existence and nature of the warm absorbers. We describe circumstances in which a stable warm absorber can exist as a multiphase medium or one with continuous variation in pressure. In particular, we find the following results: i) the warm absorber exists only if the spectral index of the x-ray power-law ionizing continuum $\alpha > 0.2$ and has a multiphase nature if $\alpha \sim 0.8$, which interestingly is the spectral index for most of the observed Seyfert 1 galaxies; ii) thermal and ionization states of highly dense warm absorbers are sensitive to their density if the ionizing continuum is sufficiently soft, i.e., dominated by the ultraviolet photons; iii) absorbing gas with super-solar metallicity is more likely to have a multiphase nature; iv) the nature of the warm absorber is significantly influenced by the absence of iron and associated elements, which are produced in the later stages of star formation history in supernovae of type Ia.

The stability curve analysis is extended further by investigating the influence of a realistic AGN continuum motivated by i) theoretical considerations of the radiation coming from the accretion disk surrounding the central black hole and ii) the observational signatures of the so called *soft excess* component often seen in the sub-keV spectra of AGN after subtracting the flux due to a model power-law component. We find that the direct radiation from the accretion disk, which peaks at 10 eV, has no role in determining the physical properties of the warm absorber. The *soft excess*, on the other hand turns out to be the most important spectral component in increasing the probability of the existence of the warm absorber.

In addition to the 10^5 *and* 10^6 K phases of the warm absorber that we discuss in details throughout the thesis, some objects show signatures of a lower temperature warm absorber state at $T \lesssim 10^{4.5}$ K usually in pressure equilibrium with the higher temperature states. Among all the parameter space that we have explored, we find such a possibility of multiple phases only if the abundance of the absorbing gas is $\gtrsim 3Z_{\odot}$.

An absorbing system with super-solar metallicity exposed to an ionizing continuum with a significant *soft excess* component seems to be the best description of a warm absorber with multiple phases in pressure equilibrium with each other.

Astrophysical Applications of Light Scattering Phenomenon by Dust

Hillol K. Das

Dust grains have been detected in almost all astronomical objects from the local environment of the earth to the distant objects like galaxies, quasars, etc. The interaction of light with dust grains include two main processes, scattering and absorption of radiation. The scattered radiation has the same wavelength as the incident one and can propagate in any direction. The radiation absorbed by a grain is transformed into its thermal energy and is usually emitted at wavelengths longer than the absorbed wavelength. Both the processes contribute to extinction when radiation from celestial objects is attenuated by the foreground dust in the line of sight.

The presence of magnetic field in the galactic environment has an important effect on the dust grains. Magnetic field plays an important role in aligning the dust grains, they align themselves in the direction of the field. Since the magnetic field is supposed to be non-uniform over a wide range, the dust grains, thus, partially align themselves along some preferred direction of the field, resulting the scattered light to be partially polarized. The presence of an empirical correlation between extinction and polarization shows that the same dust grains are responsible for both extinction and polarization.

With the help of observations it is possible to investigate extinction and polarization. Most of the polarimetric observations for this thesis have been made with the 2 m optical telescope at IUCAA Girawali Observatory (IGO). The telescope has a 2 metre aperture f/3 primary of Astro-Sital, and a Ritchey-Chretien optics to get a focal ratio of 10 at the Cassegrain focal station. A corrector is available to get $< 0.6''$ images upto a field radius of $21'$ in the optical band. Alt-az mount, with gear drives and tape encoders are used to get a pointing accuracy of $2''$, and an autoguider is available for sub-arcsec tracking.

Interpretation of the observation data requires modelling the dust grains with the right chemical compositions in the right proportions, their shape, size and their scattering mechanism. Spherical grains do not explain interstellar polarization, and thus, one requires a theory to treat non-spherical particles. The methods and techniques for effective treatment of light scattering by non-spherical particles have developed tremendously over the last few years. For astrophysical applications, the most important ones are, the separation of variables method for spheroidal shaped particles, the T-matrix method for axially shaped particles and the discrete dipole approximation method. The observed data in this thesis have been interpreted using separation of variables method.

This thesis is mainly devoted to the design and fabrication of instruments for polarimetric studies, observations and dust modelling.

The thesis has been divided into five chapters as follows:

Chapter 1 begins with an introduction to the subject of interstellar medium (ISM), dating back to as early as 1785, when Sir W. Herschel first discovered obscuring bodies in the sky, till recent times when space explorers are being sent into deep space to obtain samples of the ISM. It talks about the different composition of the ISM, mainly the interstellar gas and interstellar dust which gives rise to different observable phenomena. Emphasis has been laid on the importance of dust study, their distribution in the galaxy and their chemical composition. The depletion and abundances of various elements in the solar neighbourhood have also been discussed.

Chapter 2 discusses the observable phenomena due to the interaction of light with dust grains with special emphasis on extinction and polarization. The nature of the extinction curve at different wavelengths has been discussed and also its variation at different dusty regions. An empirical relation to fit the different extinction curve proposed by Fitzpatrick, Serkowski's relation to fit the observed polarization curve has also been discussed, with a note on polarization efficiency and its upper limit. For the observed light to be polarized, the scattering dust grains should be aligned with respect to the ambient magnetic field present in the galactic environment. Lastly, the different alignment mechanisms have been discussed with special emphasis on the Davis-Greenstein mechanism, superparamagnetic alignment, suprathermal spin mechanism and the radiative torque mechanism. The chapter ends with a note on polarimetry and the type of optical components that would be required to measure the degree of polarization of the scattered light.

In **Chapter 3** the various instruments developed for polarimetric studies as well as non-polarimetric studies, in both photometric and spectroscopic modes, which would be used with the IGO telescope have been described. The theory underlying the design of IFSOC, different glass selection criteria and the anti-reflection coatings have been discussed. The different properties of the available dispersing elements of IFOSC (grisms), filters, slits and the CCD used have also been discussed. The calibration unit developed at IUCAA for calibrating the observed spectrum and, the different lamps available for calibration and flat fielding are also discussed. The chapter ends with a note on the polarimetric components, *i.e.*, the half-wave plate and Wollaston prism mount's design and assembly, and several test results.

Chapter 4 discusses the different observations made, firstly, to calibrate the polarimeter and secondly, the observations of two target stars, HD179406 and HD147165. These stars are of special significance for dust modelling analysis, because they are behind single clouds and so analytical interpretation of their observed data is relatively simple. The observed spectra (both ordinary and extra-ordinary) and also the observed degree of linear polarization are presented in details. Serkowski curve was also compared with observed polarization data for both the stars. The polarization efficiency of the two stars was then obtained, which was used in the next chapter for dust model analysis.

In **Chapter 5**, an attempt is made to interpret the different observed data with the help of various dust models and alignment mechanism. In the beginning, two alignment mechanisms of primary importance are discussed, perfect Davis-Greenstein alignment and then the imperfect Davis-Greenstein alignment in more details; the importance of several alignment parameters are also discussed. Having described the reason for choosing amorphous carbon, astronomical silicate and graphite as the dust material, the normalized extinction and polarization efficiency obtained from our models was compared with observations for stars HD147165, HD179406, HD147933, HD197770 and HD99264; rotating prolate and oblate spheroidal particles were considered in our work.

Finally, **Chapter 6** gives a summary of the work done in all the three broad aspects; instrumentation, observations and dust modelling. The direction for future work is also discussed in this chapter.

Studying the Properties of Intermediate Redshift Galaxies Using Large Surveys

Abhishek Rawat

Determining how galaxies formed and evolved is one of the outstanding problems of modern astrophysics. There is growing evidence for galaxy evolution out to $z \sim 1$. A striking result in the exploration of the distant universe is that the Hubble classification sequence is no longer appropriate for describing galaxies when the universe was only half its present age, with galaxy morphologies often seen to be irregular and complex. Such strong evolution could be related to the rapidly increased frequency of galaxy mergers at earlier epochs.

In the current age, astronomy is driven increasingly by large surveys of the observable universe using some of the best telescope facilities in the world working at various wavelengths. Such surveys are the result of years of work by large teams of scientists. The data from most of these surveys is public and is freely available to the greater astronomical community across the world. Such surveys usually cover a large area on the sky and hence, provide vast amounts of valuable data on celestial objects, which make them ideal for studying the statistical properties of objects such as galaxies or the large scale structure of the universe. Given the fact that the typical sizes of galaxies at moderate redshifts is less than the seeing disk, even at the best observatory sites on Earth, most of the surveys of the distant universe have, therefore, been the exclusive purview of the Hubble Space Telescope (HST). The installation of the Advanced Camera for Surveys (ACS) on board the HST in March 2002, has led to a flurry of large area, deep, multiwavelength surveys of the distant universe, all available in the public domain.

As part of my Ph.D. thesis, Abhishek Rawat has worked on galaxy evolution over the intermediate redshift range utilizing the wealth of data available from these latest generation of public surveys. He has used various techniques, such as quantitative galaxy morphology, stellar population synthesis, star formation rate estimation, spectral analysis of galaxies and precision photometry, etc., and have utilized multiwavelength data ranging from radio, mid-IR, near-IR, optical to x-rays. As part of this thesis, he has worked on several related, but complementary projects, with the common aim of furthering the understanding of galaxy evolution over the last $\sim$ 8Gyr.

Luminous Compact Galaxies (LCGs) constitute one of the most rapidly evolving galaxy populations over the last $\sim$ 8Gyr history of the universe. Due to their inherently compact size, any detailed quantitative analysis of their morphologies has proved to be difficult in the past. Hence, the morphologies and the local counterparts of these enigmatic sources have been hotly debated. As part of this thesis, Rawat has used the high angular resolution, deep, multiband HST/ACS imaging data from the HST/ACS *Great Observatories Origins Deep Survey* (GOODS) to study the quantitative morphology of a complete sample of LCGs in the redshift range $0.5 \le z \le 1.2$. In addition to quantitative morphologies, he has used complementary data available at various wavelengths (near-IR to Mid-IR) to discern properties such as stellar masses and star formation rates (SFR) of our sample LCGs and has tried to figure out their possible counterparts in the local universe.

Galaxy mergers are believed to be the chief mechanism driving galaxy evolution within the hierarchical framework. Although, mergers are rare at the current epoch, the hierarchical framework predicts that the merger rate must have been higher at earlier epochs. Despite its importance in understanding galaxy evolution, the quantification of the galaxy major merger rate and its evolution with redshift is still an ill constrained and hotly debated issue, with conflicting results being reported in the literature. He has used a combination of deep, high angular resolution imaging data from the *Chandra Deep Field South* (CDFS) half of the HST/ACS GOODS survey and ground based near-IR K_s images to derive the evolution of the galaxy major merger rate in the redshift range $0.2 \le z \le 1.2$. His work provides a robust estimate of the major merger rate upto redshift ~ 1.2 using a representative sample of near-IR selected galaxies, which are well within the photometric completeness of the source catalogues.

Before extending the work to higher redshifts, there are some caveats to be addressed. Much of the knowledge about the properties of high redshift galaxies has been acquired from studying Lyman Break Galaxies (LBGs) at redshift $\sim$ 3.0 - 5.0, identified in one of the numerous HST surveys. Since, most of the (relatively) large area detectors on HST which have been used for these surveys work in the optical, they are probing the rest-frame UV light of LBGs at these redshifts. Deriving morphological information about a galaxy from its rest-frame UV light can be misleading, as this light is mainly dominated by patchy star forming regions and is not representative of the underlying galaxy mass distribution. In this thesis, he has utilized the HST/WFPC2 F300W band observations obtained in parallel with the HST/ACS Ultra Deep Field (UDF), which constitute the deepest image of the UV sky ever obtained, along with the HST/ACS GOODS images to *quantify* the biases expected if one derives the morphology of an object based on the rest-frame UV light, as is done in most high redshift work related to LBGs.

Physics of Structure Formation and Intergalactic Medium

Saumyadip Samui

In this thesis, Saumyadip Samui has built a self-consistent semi-analytical model of star formation, luminosity function (LF), reionisation and galactic outflows in the framework of Lambda cold dark matter (LCDM) cosmology. These models are used to understand various observations related to high redshift universe such as star formation, luminosity functions, reionization, metals in the inter galactic medium (IGM) and physical conditions of the IGM. The semi-analytical approach is motivated by the need to explore the sensitivity of our results to the model parameters in an extensive fashion.

The first issue he has studied in detail in this thesis is the star formation and UV luminosity function of high redshift galaxies. He hasd use the analytically motivated Press-Schechter (PS) halo mass function and the Sasaki formalism to get the formation rate of dark matter halos and their subsequent survival probabilities, for most of the work. However, he has also explored other halo mass functions that are obtained from various numerical N-body simulations like Sheth-Tormen (ST) halo mass function. For these cases he has taken the derivative of the mass function to model the net formation rate of halos.

He has assumed that the star formation rate in an individual halo first increases linearly and then falls of exponentially with a time scale of the order of dynamical time scale of the halo. The star formation rate is converted to UV luminosity, assuming some initial mass function (IMF) of the stars formed. Samui has constrained the model parameters related to star formation by fitting the observed UV luminosity functions of high-z Lyman break galaxies (LBGs). He has considered two models of star formation: (i) the 'atomic cooling' model, in which the star formation occurs only in high mass halos that can cool with radiative recombination of atoms, and (ii) the 'molecular cooling' model, where the star formation can take place also in small mass halos that can only cool in presence of H_2 molecules. He has self-consistently solved for the reionization history of the universe in order to calculate the radiative feedback at different redshifts.

For the cosmological parameters favoured by the Wilkinson Microwave Anisotropy Probe (WMAP) data, his models consistently reproduce the electron scattering optical depth to reionization, redshift of reionization and the observed luminosity functions (LF) and hence, the star formation rate (SFR) density at $3 \leq z \leq 7.4$ for a reasonable range of model parameters. The feedback due to photoionization is sufficient to explain the flattening of the LF at low luminosity end. Models with prolonged continuous star formation activities are preferred over those with short bursts, as they are consistent with the existence of a Balmer break in considerable fraction of observed galaxies even at $z \sim 6$. The halo number density evolution from the standard LCDM structure formation model that fits LF up to $z \sim 7$ is consistent with the upper limits on source counts at $8 \lesssim z \lesssim 12$ obtained from the Hubble Ultra Deep Field (HUDF) observations without requiring any dramatic change in the nature of star formation. However, to reproduce the observed LF at $6 \lesssim z \lesssim 10$, obtained from the near-IR observations around strong lensing clusters, we need a strong evolution in the initial mass function, reddening correction and the mode of star formation at $z \gtrsim 8$.

He has shown that low-mass molecular cooled halos, which may be important for reionizing the universe, are not detectable in the present deep field photometric observations even if a considerable fraction of its baryonic mass goes through a star burst phase. However, their presence and contribution to reionization can be inferred indirectly from the redshift evolution of the LF in the redshift range $6 \lesssim z \lesssim 12$. In the model calculations, the contribution of low-mass halos to global SFR density prior to reionization reveals itself in the form of second peak at $z \gtrsim 6$. However, this peak will not be visible in the observed SFR density as a function of z as most of these galaxies have luminosity below the detection threshold of various ongoing deep field surveys.

Using the χ^2 minimization technique, he has shown that the shape of the UV luminosity functions of LBGs in the redshift range $3 \leq z \leq 7.4$ are better reproduced by the models using the Sheth-Tormen halo mass function compared to the models with the PS halo mass function. However, the best fit parameters related to the star formation model at different redshifts depend crucially on the observational data set that one uses. Further, the predicted LFs are similar for two ways of calculating the formation rate of halos, namely from the Sasaki formalism or using the derivative of the mass function.

Next, he has calculated the Lyman-α LFs of high redshift galaxies from the star formation model, assuming case B recombination. He has shown, by comparing UV luminosity functions of LBGs and Lyman-α emitters (LAEs), that only $\lesssim 10\%$ of LBGs are detected in Lyman-α emission with rest equivalent width greater than the limiting equivalent width of the narrow band surveys at $z \lesssim 4$. Predicted fraction of LBGs that are LAEs in this redshift is consistent with the spectroscopic observations at $z \sim 3$. However, the observed UV luminosity function of LAEs at $z > 5$ can be reproduced only when we assume that nearly all LBGs are Lyman-α emitters. Thus it appears that $4 < z < 5$ marks the epoch when a clear change occurs in the physical properties of the high redshift galaxies. As Lyman-α escape depends on dust and gas kinematics of the inter stellar medium (ISM), this could mean that on an average the ISM at $z > 5$ could be less dusty, more clumpy and having a more complex velocity field. He has shown that the evolution in the Lyman-α LF for $z \gtrsim 5.7$ is consistent with halo number density evolution without any drastic change in the nature of star formation and escape of Lyman-α photons. In particular, upto $z = 6.5$, we do not see the effect of evolving IGM opacity on the Lyman-α escape from these galaxies. His models also predict an increase in the average equivalent width of the Lyman-α emission with decreasing redshift.

He has next modelled thermally driven galactic outflows originating from the supernova (SNe) explosions in the star forming galaxies in order to explain the presence of metals in the low density IGM traced by the Lyman-α forest. The star formation model has already been constrained by fitting the UV luminosity functions of LBGs.

Galactic outflows are modelled in a manner akin to models of stellar wind-blown bubbles. The outflow is taken to be spherically symmetric and its dynamics is followed using a thin-shell approximation. It has been shown that large-scale outflows can generically escape from low-mass halos ($M \lesssim 10^9\ M_\odot$) for a wide range of model parameters, while this is not the case in high-mass halos ($M \gtrsim 10^{11} M_\odot$). The flow generically accelerates within the halo virial radius, then starts to decelerate, and traverses well into the IGM, before freezing to the Hubble flow. The acceleration phase can result in shell fragmentation due to the Rayleigh-Taylor instability, although the final outflow radius is not significantly altered. The gas-phase metallicities of the outflow and within the galaxy are computed, assuming uniform instantaneous mixing. Ionization states of different metal species are calculated and used to examine the detectability of metal lines from the outflows.

The global influence of galactic outflows is also investigated using porosity-weighted averages and probability density functions of various physical quantities. Models with star formation, only in atomic cooled halos significantly fill the IGM at $z \sim 3$ with metals ($-2.5 \gtrsim [Z/Z_\odot] \gtrsim -3.7$), the actual extent depending on the efficiency of winds, the initial mass function and the fractional mass that goes through star formation. The reionization history has a significant effect on the volume filling factor, due to radiative feedback. In these models, a large fraction of outflows at $z \sim 3$ are supersonic, hot ($T \geq 10^5$ K) and have low density, making metal lines difficult to detect. They may also result in significant perturbations in the IGM gas on scales probed by the Lyman-α forest.

On the contrary, models including molecular cooled halos with a normal mode of star formation can potentially volume fill the universe at $z \sim 8$ without unduly disturbing the observable properties of the Lyman-α forest, thereby, setting up a possible metallicity floor ($-4.0 \lesssim [Z/Z_\odot] \lesssim -3.6$). The fluctuations of order unity at $z \sim 8$ that become the mildly non-linear fluctuations traced by Lyman-α forest at $z < 4$ will then have this metallicity. Interestingly, molecular cooled halos with a 'top-heavy' mode of star formation are not very successful in establishing the metallicity floor because of the additional radiative feedback that they induce.

It has been shown that the volume filling factor of outflows varies very weakly between models with different halo mass functions. It depends strongly on the way we treat the destruction rate of halos and associated wind bubbles. Physical properties related to the outflow affected regions are not very sensitive to differences in the halo mass functions.

Finally, Sami has considered the possibility of galactic winds driven by a relativistic cosmic ray (proton) component in addition to the hot thermal gas component. The cosmic rays (CRs) are likely to be efficiently generated in SNe shocks. He has constructed solutions of such CR driven free winds from galaxies, whose gravitational potential is of the Navarro-Frenk-White (NFW) form. Cosmic rays naturally provide the extra energy and/or momentum input to the system needed for a transonic wind solution in a gas with adiabatic index $\gamma = 5/3$. These wind solutions predict an asymptotic wind speed closely related to the circular velocity of the galaxy. They also predict an anti-correlation between the mass loading of the wind and the circular velocity of the galaxy. The mass outflow rate per unit star formation rate is inversely proportional to the square of the circular velocity. These features could have important implications for the models of metal enrichment of the IGM.

Quantum Effects and Thermodynamics of Horizons in Strong Gravitational Field

Sudipta Sarkar

The main theme of contemporary theoretical physics is to seek a theory of everything as a putative theory that fully explains and links together all known physical phenomena. In the current mainstream physics, a Theory of Everything would unify all the fundamental interactions of nature. In the last few decades, the quest for an unified theory resulted in a standard model for particle physics which, using the language of quantum field theory, successfully describes all the basic interactions, except gravity. When we leave out the effects of gravity, it is possible to provide a self consistent picture of the other interactions, with a master Lagrangian of the standard model, that is capable enough to explain all the features. Such an interpretation is now firmly established.

The situation changes radically once the effects of gravity are taken into consideration. In classical picture, gravity is the manifestation of the curvature of spacetime manifold, where the dynamics is obtained by solving Einstein's field equations with appropriate energy-momentum tensor. This makes gravity radically different from other interactions like electromagnetism even in the classical level. These differences ultimately lead to enormous technical and conceptual problems for any effort to unify gravity with quantum rules. A partial list of such issues are:

- The Lagrangian describing classical gravity, treated as a function of linearized metric is not perturbatively renormalizable; in fact, there is no simple redefinition of the field variables, which will lead to a perturbatively renormalizable theory. As a result, it is not possible to construct a renormalizable quantum field theory for gravity.

- Any reasonable description of gravity will have a geometrical structure and the gravitational field will affect the spacetime intervals in a specific manner. Therefore, in General Relativity, the spacetime itself is dynamical. There is no preferred coordinates and no natural spatial surfaces. This induces famous conceptual problems like definition of "time" in quantum gravity.

- Gravity affects the light signals and hence, determines the causal structure of spacetime. In particular, gravity is capable of generating regions of spacetime from which no information can reach the outside world through classical propagation of signals. Existence of such regions has no parallel in any other interaction. The data regarding quantum fields in these regions is inaccessible to an external observer and this requires reformulation of the equations of quantum field theory, possibly by tracing over the information in the inaccessible regions, something which is difficult to do both mathematically or conceptually.

- The principle of equivalence implies that all energies gravitate, thereby, removing the ambiguity in the zero level for the energy, which exists in non-gravitational interactions. This feature also suggests that there is no such thing as a free, non-interacting field. As a result, in the presence of gravity, standard technique of normal ordering is no longer applicable.

These features create problems even when one tries to develop a quantum field theory in an external classical gravitational background. Conventional quantum field theory works best when a static causal structure, global Lorentz frame, asymptotic in-out states, bounded Hamiltonians and the language of vacuum state, particle excitations, etc. are supplied. The gravitational field removes all of these features, strongly hinting that we may be working with an inadequate language. Perturbative language, which at best gives an algorithm to calculate S-matrix elements, is not going to be of much use in understanding the quantum structure of gravitational field. Most of the interesting questions – possibly all the interesting questions in quantum gravity are non perturbative in character.

On the other hand, such a study of the dynamics of quantum field in a non-trivial curved background leads to several intriguing features, which are expected to survive even in a final quantum gravity theory. The most important among these results are the thermal properties of spacetime horizons and notion of entropy associated with them. Existence of black hole entropy, Hawking temperature and striking similarities of the laws of black hole mechanics with laws of thermodynamics compel us to re-examine the deep connection between gravity, quantum theory and thermodynamics. A natural question arises in this context: *how do the laws of General Relativity, which is a geometric theory on a differential manifold, know about the laws of thermodynamics?* It is difficult to find a satisfactory answer of this question within the standard paradigm and one needs to go beyond the conventional way of looking towards gravity.

Then a possibility arises where gravity can be treated as an emergent phenomenon like thermodynamics resulted from the quantum statistical mechanics of spacetime microstructure. This is like assuming that spacetime is analogous to an elastic solid and equations describing its dynamics are similar to those of elasticity. Such a paradigm to understand the dynamics of gravity was first suggested by Sakharov, and if this picture is correct, then one should be able to link the equations describing bulk spacetime dynamics with horizon thermodynamics. There have been several approaches which have attempted to do this with different levels of success. The most explicit demonstration of this is due to Padmanabhan's work in which, Einstein's field equations can be interpreted as a thermodynamic relation $TdS = dE + PdV$ arising out of virtual displacements of the horizon. This result provides an alternative route to understand the dynamics of gravity where, classical gravity is a thermodynamic, long wavelength limit of the underlying statistical mechanics of spacetime.

But, if General Relativity is regarded as a low energy effective theory, it is natural to expect *quantum corrections* to the Einstein-Hilbert action functional which will, of course, depend of the nature of the microscopic theory but generally involve higher derivative correction terms. In particular, such terms also arise in the effective low energy action of string theories. The theory of black hole thermodynamics for such higher derivative actions are well established due to the works by Wald, Jacobson, Myers and collaborators. All the important notions like black hole entropy, Hawking temperature can be consistently defined. It turns out that, for any theory other than General Relativity, the proportionality between black hole entropy and horizon area is no longer valid and in general, the entropy is the Noether charge associated with diffeomorphism symmetry of the action functional, constructed out of local quantities. If the thermodynamics route to understand the gravitational interaction has any grain of truth, one must be able to extend such ideas for more general actions and show that such an interpretation *transcends Einstein gravity and is applicable even in this more general case.*

The thesis titled, "***Quantum effects and thermodynamics of horizon in strong gravitational field***" by Sudipta Sarkar under the guidance of T. Padmanabhan is focused towards these issues involving the study of horizon thermodynamics and its extension to higher derivative gravity. As a part of these, the thesis discusses the extension of the thermodynamic route to understand gravity for higher derivative actions, derivation of Hawking radiation by tunneling method and the semi-classical evaluation of subleading correction terms to black hole entropy.

A summary of the thesis is as follows:

The thesis, first introduces some elementary concepts of quantum field theory in curved spacetime, which is the starting point for the topics covered in this thesis. In particular, this chapter reviews the essential properties of a Killing horizon, formal derivation of the laws of black hole thermodynamics and discusses various methods of calculating black hole entropy with main emphasis on the semi-classical brick wall model due to 't hooft. Then, it presents the extension of black hole thermodynamics in higher derivative gravity theories with illustration of Lancos-Lovelock Gravity as the most obvious higher derivative generalization of Einstein-Hilbert action functional. Next, the thesis discusses the extension of the thermodynamics route to gravity for spherically symmetric D-dimensional Lancos-Lovelock Gravity. These suggest that the thermodynamic route to gravity is a generic approach, which is applicable beyond the Einstein-Hilbert action. The thesis also deals with the extension of these ideas for non-spherically symmetric and also time dependent set-up. Also, the thesis provides an extensive review of the tunneling mechanism for Hawking radiation and offers a generalized derivation based on energy conservation for a spherically symmetric horizon. Such a study interestingly leads to a curious relationship between tunneling calculations and first law of thermodynamics written in the form $TdS = dE + PdV$. The analysis is applicable to any reasonable theory of gravity as long as the first law of thermodynamics for horizons holds. At the end, the thesis explore the case of black hole entropy, adopting the semi-classical brick wall formalism and compute the brick wall entropy of a quantum scalar field around static and spherically symmetric black holes at the higher orders in the WKB approximation. It was found that the brick wall model generally predicts power law and logarithmic corrections to the Bekenstein-Hawking entropy in all spacetime dimensions. The results for specific black hole solutions are presented and compared the presence of various sub-leading terms with other approaches. Finally, the thesis summarizes the main conclusions and some implications suggested by the present work.

Confronting Cosmological Models with Observations

Arman Shafieloo

The work related to his Ph.D. thesis has been on implementing and applying different non-parametric, model-independent statistical methods for analyzing cosmological data, with the purpose of reconstructing important cosmological quantities and parameters. These methods have been applied to the most recent cosmological data sets such as the WMAP data on cosmic microwave background anisotropy, the GOLD and SNLS supernovae data, and to the results from detection of baryon oscillations. His research has been primarily focused on applying some advanced statistical methods (the improved Richardson-Lucy deconvolution method, wavelet analysis, smoothing methods) in two important areas in cosmology. The main questions which he has addressed in the thesis are :

Non-parametric recovery of the shape of the primordial power spectrum directly from observations.

Non-parametric reconstruction of the expansion history of the universe and of the properties of dark energy.

The model-independent reconstruction of cosmological quantities, can be used to examine dierent cosmological models against observations without biasing the results with any initial model assumption.

Origin and Evolution of Cosmic Magnetic Fields

Sharanya Sur

Coherent large-scale magnetic fields are observed in many astrophysical objects ranging from planets, stars, galaxies and galaxy clusters. Theoretical studies aimed at addressing the question of how such large-scale magnetic fields are generated and maintained is based on the Mean-Field Dynamo (MFD) theory. In the MFD theory, one uses the magneto-hydrodynamic equations to derive equations for mean velocity and magnetic fields using a suitable averaging procedure. The central importance to MFD theory is the mean turbulent electromotive force $\overline{\boldsymbol{\mathcal{E}}}$, which represents the effect of turbulent correlations on the mean magnetic field. Expressing $\overline{\boldsymbol{\mathcal{E}}}$ in terms of the mean magnetic field and it's derivatives requires closure approximations. These approximations yield the dynamo coefficients - the α-effect and the turbulent magnetic diffusivity $\eta_{\rm t}$, both of which are argued to be related to the statistical properties of the turbulent flow. The α-effect is a crucial driver of mean-field dynamos, while $\eta_{\rm t}$ enhances mean magnetic field diffusion. In spite of being studied quite extensively for the past few decades, several potential problems associated with the dynamo paradigm still remain to be explained. The main focus of this thesis is to address some of these potential problems. Apart from this, the work presented here also explores the possibility of large-scale dynamo action arising from other effects, not directly related to mechanisms of the standard MFD paradigm.

The first issue that we studied in detail is the question of whether one can relate the turbulent transport coefficients namely, the α-effect and $\eta_{\rm t}$ to the statistical properties flow in the kinematic regime. The core of this issue is the fact that the very definition of these transport coefficients is based on closure approximations like the First-order smoothing approximation (FOSA) and the Minimal-τ approximation (MTA). In the kinematic regime, both FOSA and MTA yield an α-effect proportional to the kinetic helicity of the turbulence. But, the applicability of such approximations become questionable for large magnetic

Reynolds number (R_m) systems. In such systems, the small-scale dynamo produces random magnetic fields at a rate much faster than the mean-field. Moreover, the correlation time of the turbulence measured in units of the eddy turnover time is not small for turbulent flows. Thus, the relation between the transport coefficients and the statistical properties of the flow becomes unclear. Some earlier numerical simulations suggested that even in the kinematic regime, the relation is complicated and R_m dependent.

To clarify this R_m dependence of the transport coefficients, Sharanya Sur has used direct numerical simulations of helically forced turbulence. In the simulation, the α-effect and η_t are computed using the the *Test-field* method. It is hsown that in the kinematic regime, up to moderate $R_\mathrm{m} \sim 220$, homogeneous, isotropic, helical turbulence leads to an α-effect and η_t, whose values are independent of R_m, for $R_\mathrm{m} > 1$. These turbulent coefficients also turn out to be consistent with expectations from simple closure approximations. Moreover, as expected for small values of R_m, we find that the α-effect and η_t are proportional to R_m. Over finite time intervals, meaningful values of α and η_t can be obtained even when there is small-scale dynamo action that produces strong magnetic fluctuations. This suggests that the fields generated by the small-scale dynamo do not make a correlated contribution to the mean emf.

Next, he has studied one of the long standing problems in the MFD theory, which is related to the effect of nonlinear backreaction on the transport coefficients. The backreaction occurs when the Lorentz force becomes strong enough to affect the fluid motions. Several authors have argued that this backreaction leads to the modification of the α-effect by a term proportional to the current helicity of the small-scale field. But there has been counter arguments that such modification of the α-effect is only possible if a small-scale field pre-existed even in the absence of a mean-field. Resolving this issue is crucial as this will help us to understand the saturation behaviour of turbulent dynamos.

He has approached this problem by exploring an exactly solvable model of nonlinear dynamos in the limit of small fluid and magnetic Reynolds numbers, i.e, for $\mathrm{Re}, R_\mathrm{m} \ll 1$. The advantage of this approach lies in the fact that it allows for exact solutions of the induction and momentum equation, which enables one to express the small-scale magnetic and velocity fields in terms of the forcing. Utilizing this freedom, he has shown that the nonlinear α-effect can be expressed in several equivalent forms in agreement with formalisms that are used in various closure schemes. On one hand, it is possible to express α completely in terms of the helical properties of the velocity field (normally done in FOSA), or, alternatively, as the sum of two terms, a so-called kinetic α-effect and an oppositely signed term proportional to the helical part of the small scale magnetic field. These results hold for both steady and time-dependent forcing at arbitrary strength of the mean-field. In addition, we also consider the τ-approximation closure in the limit of $\mathrm{Re}, R_\mathrm{m} \ll 1$. The underlying equations are then identical to those used under FOSA, but they reveal interesting differences between the steady and time-dependent forcing. For steady forcing, the correlation between the forcing function and the small-scale magnetic field turns out to contribute in a crucial manner to determine the net α-effect. However for delta-correlated time-dependent forcing, this force-field correlation vanishes, enabling one to write α exactly as the sum of kinetic and magnetic α-effects, similar to what one obtains in the large Reynolds number regime in the τ-approximation closure hypothesis. In the limit of strong imposed fields B_0, we find $\alpha \propto B_0^{-2}$ for delta-correlated forcing, in contrast to the well-known $\alpha \propto B_0^{-3}$ behaviour for the case of a steady forcing. Our analysis is also shown to be in agreement with numerical simulations of steady as well as random helical flows.

The addition of a magnetic alpha to the kinetic alpha has profound implications for large-scale dynamo action. These implications stem from the fact that magnetic helicity is conserved in high R_m systems. Such a conservation law leads to the production of equal and opposite amounts of helicity in the large- and small-scale fields. The current helicity associated with the growing small-scale field contributes to the magnetic alpha (α_m) which begins to suppress the total α-effect, eventually quenching the dynamo. Therefore, to explain how coherent magnetic fields exist in astrophysical systems like galaxies, one has to search for mechanisms that are capable of shedding the small-scale magnetic helicity.

In this context, we study the influence of various kinds of magnetic helicity fluxes on galactic dynamos. For simplicity, we use a simple, semi-analytical model appropriate to galaxies. At first, we consider a model of nonlinear dynamos with the dynamo equations reduced to a nonlinear system of ordinary differential equations in time using the no-z approximation. The results obtained from the no-z approximation model is compared wherever possible, with one-dimensional model of galactic dynamos, where the partial differential equations (PDE's) of the system are solved numerically. They discuss the implications and interplay of two types of magnetic helicity flux, one produced by advection (e.g., due to the galactic fountain or wind) and the other - the Vishniac-Cho flux, arising from anisotropy of turbulence and shear. He has argued that the latter is significant if the galactic differential rotation is strong enough. It is also confirmed that the intensity of gas outflow from the galactic disc optimal for the dynamo action is close to that expected for normal spiral galaxies. The steady-state strength of the large-scale magnetic field supported by the helicity advection is still weaker than that corresponding to equipartition with the turbulent energy. However, the Vishniac-Cho helicity flux can boost magnetic field further to achieve energy equipartition with turbulence. For stronger outflows that may occur in starburst galaxies, the Vishniac-Cho flux can be essential for the dynamo action. However, this mechanism requires an initial large-scale magnetic field of at least $\simeq 1\mu$G to be launched, so that it has to be preceded by a conventional dynamo assisted by the advection of magnetic helicity by the fountain or wind.

Apart from addressing some of the crucial problems in MFD theory, he has also explored other avenues leading to large-scale dynamo action. One of these is to examine whether random fluctuations in the kinetic part of the α-effect can lead to large-scale dynamo action. This is studied again in the context of the galactic dynamo. Two different probability distribution functions (PDFs) were examined for the stochastic α. The first choice is simpler, where the stochastic α can take values either $+\alpha_s\, f(z)$ or $-\alpha_s\, f(z)$ with equal probability. This kind of PDF was also assumed by Sokoloff 1997. Here α_s is the amplitude of the stochastic α and $f(z) = \sin(\pi z)$ takes care of the symmetry condition across the midplane of the disc. In the second, we take the PDF of the stochastic α to be a Gaussian. It is found that in both the cases, the strength of the mean-field varies significantly from one realization to another. Thus, it becomes essential to examine a large number of realizations in order to make any deductions about the efficiency of the stochastic $\alpha\omega$-dynamo.

The net growth or decay of the field depends not only on the dynamo parameters but also on the particular realization, the correlation time of the stochastic α compared to turbulent diffusion timescale and the time over which the system is evolved. Using the PDF similar to that of Sokoloff 1997, we find that for a long correlation time of the stochastic α, the dynamo is capable of generating large-scale fields in about 65% of the realizations for supercritical values of the dynamo number. But, for the same value of the dynamo number, the dynamo becomes less efficient when the correlation time of the stochastic α is short. The same exercise has been repeated for a stochastic α now chosen from a Gaussian PDF. Here, we concentrate on models with a short correlation time for the stochastic α. It is shown that for higher dynamo numbers, growth is sustained for longer times and for a larger number of realizations. Beyond a certain critical value of the dynamo number that happens to be around $|D| \sim 160 - 180$, all realizations show secular growth. For dynamos where both a coherent and fluctuating α are present, the stochasticity of α can help alleviate catastrophic dynamo quenching, even in the absence of helicity fluxes. One can obtain final field strengths up to a fraction ~ 0.01 of the equipartition field $B_{\rm eq}$ for dynamo numbers $|D| \sim 40$, while fields comparable to $B_{\rm eq}$ require much larger degree of α fluctuations or shear. This type of dynamo may be particularly useful for amplifying fields in the central regions of disc galaxies. Finally, Sur has explored the possibility of large-scale dynamo action arising due to cross helicity in a simple non-helical flow. This flow, known as the Archontis flow, is a generalization of the Arnold–Beltrami–Childress (ABC) flow, but with the cosine terms omitted. Direct numerical simulations of such flows demonstrate the presence of magnetic fields on scales larger than the scale of the flow. Further, we find that the mean emf due to the cross helicity effect is proportional to the mean magnetic field and therefore, leads to its exponential amplification for $R_{\rm m}$'s exceeding a certain critical value. However, the late saturation behaviour deviates from that of a conventional α^2 dynamo. In contrast to magnetic helicity conservation, the small-scale cross helicity is not conserved even in the ideal limit due to the presence of the forcing term in the momentum equation. This leads to a non-zero correlation of the driving force with the magnetic field. This eventually produces a net cross helicity that along with the mean vorticity that contributes to the mean emf to generate large-scale magnetic fields.

(IV) PUBLICATIONS

(a) By IUCAA Resident Members

The publications are arranged alphabetically by the name of the IUCAA Resident Member, which is highlighted in the list of authors. When a paper is co-authored by an IUCAA Resident Member and a Visiting Associate of IUCAA, the name of the latter is displayed in italics.

Journals

Joydeep Bagchi, *Joe Jacob*, Gopal Krishna, Norbert Werner, Nitin Wadnerkar, Jaydeep Belapure and A. C. Kumbharkhane (2009) A diffuse bubble-like radio-halo source MRC 0116+111 : Imprint of AGN feedback in a low – mass cluster of galaxies, MNRAS, **399**, 601.

R. J. van Weeren, H. J. A. Rottgering, **J. Bagchi,** et al. (2009) Radio observations of ZwCI 234. 1 + 0000 : A double radio relic cluster, A & A, **506**, 1083V.

B. Bhattacharyya, Y. Gupta, and J. Gil (2010) Investigation of the unique nulling properties of PSR B0818-41, MNRAS, **408**, 407.

T. Munoz-Darias, S. Motta, D. Pawar, T. Belloni, **D. Bhattacharya** (2010) The hard state of black hole candidates : XTE J1752-223, MNRAS, **404**, L94.

Pandey, S. B., et al (27 authors including **K. Misra**, **A. N. Ramaprakash**, **V. Mohan** and **D. Bhattacharya**) (2009) Multi-wavelength observations of the GRB 080319B afterglow and the modeling constraints, A & A, **504**, 45.

Bhattacharya D. (2009) Frontiers in Space Astronomy, Current Science, **97**, 785.

Naresh Dadhich and O. B. Zaslavskii (2009) Focusing and defocusing of truly naked black holes, Int. J. Mod. Phys., D **18**, 1073.

Alfred Molina and **Naresh Dadhich**, (2009) On Kaluza-Klein spacetime in Einstein-Gauss-Bonnet gravity, Int. J. Mod. Phys., D **18**, 599.

Naresh Dadhich (2009) Universal velocity and universal force, Physics News, **39**, 20.

I. P. Neupane and **Naresh Dadhich** (2009) Entropy bound and causality in higher curvature gravity, Class. Quant. Grav. **26**, 015013.

Kartik Prabhu and **Naresh Dadhich** (2010) Energetics of a rotating black hole in 5 - dimensional supergravity, Phys. Rev. D **81**, 024011.

H. K. Das, N. V. Voshchinnikov and V. B. Ilin (2010) Interstellar extinction and polarization a spheroidal dust grain approach perspective, MNRAS, **404**, 265274.

G. C. Dewangan, R. Misra, A. R. Rao and R. E. Griffiths (2010) Associated spectral and temporal state transition of the bright ULX NGC1313 X-1", MNRAS, **407**, 291.

H. Mukhopadhyay, H. Tagoshi, **S. V. Dhurandhar** and N. Kanda (2009) Detecting gravitational waves from inspiraling binaries with a network of geographically separated detectors : Coherent versus coincident strategies, Phys. Rev. D, **80**, 123019.

S. V. Dhurandhar (2009) Time-delay interferometry and the general relativistic treatment of LISA optical links, JPCS, **154**, 012047.

S. V. Dhurandhar, LIGO Science Collaboration and Virgo Collaboration (2009) An upper limit on the stochastic gravitational wave background of cosmological origin, Nature, **460**, 990.

S. V. Dhurandhar, LIGO Science Collaboration and Virgo Collaboration (2009) Searches for gravitational waves from known pulsars with S5 LIGO data, Ap. J. **713**, 671.

S. Dhurandhar, K. R. Nayak and J-Y. Vinet (2010) Time-delay interferometry for LISA with one arm dysfunctional, Class. and Quant. Grav. **27**, 135013.

P Barriga, et. al. (including **S. Dhurandhar** and **T. Souradeep**) (2010) AIGO : A southern hemisphere detector for the worldwide array of ground based interferometric gravitational wave detectors, Class. Quan. Grav., **27**, 084005.

I. Thongkool, M. Sami, **R. Gannouji**, and *S. Jhingan* (2009) Constraining f (R) gravity models with disappearing cosmological constant, Phys. Rev. D, **80**, 043523.

Shinji Tsujikawa, **R. Gannouji**, Bruno Moraes and David Polarski (2009) The dispersion of growth of matter perturbations in f (R) gravity, Phys. Rev. D, **80**, 084044.

Amna Ali, **R. Gannouji**, M. Sami and *Anjan A. Sen*

(2010) Background cosmological dynamics in f (R) gravity and observational constraints, Phys. Rev. D, **81**, 104029.

Tuhin Ghosh, Rajib Saha, Pankaj Jain and **Tarun Souradeep** (2009) Model independent foreground power spectrum estimation using WMAP 5-year data Phys. Rev. D, **79**, 123011.

Ashim K. Roy, Subodh K. Sharma and **Ranjan Gupta** (2010) Frequency and size distribution dependence of visible and infrared extinction for astronomical silicate and graphite grains, JQSRT, **111**, 795.

A. Bora, **R. Gupta**, *H. P. Singh*, and K. Duorah (2009) Automated star-galaxy segregation using spectral and integrated band data for TAUVEX/ASTROSAT satellite data pipeline. New Astronomy, **14**, 649.

Vinu Vikram, Yogesh Wadadekar, **Ajit K. Kembhavi** and G. V. Vijayagovindan (2010) Quantitative measure of evolution of bright cluster galaxies at moderate redshifts, MNRAS, **401**, L39.

Sudhanshu Barway, Yogesh Wadadekar, **Ajit K. Kembhavi** and Y. D. Mayya (2009) Near-infrared bulge-disc correlations of lenticular galaxies MNRAS, **394**, 1991.

T. Sivarani, S. Lpine, **Ajit K. Kembhavi** and J. Gupchup (2009) SDSS J125637-022452 : A high proper motion L subdwarf, *Ap. J. Letts*., **694**, 2, L140.

Dawood Kothawala, L. Sriramkumar, S. Shankaranarayanan and **T. Padmanabhan** (2009) Path integral duality modified propagators in spacetimes with constant curvature. Phys. Rev. D **79**, 104020.

Dawood Kothawala and **T. Padmanabhan** (2010) Response of Unruh-DeWitt detector with time-dependent acceleration, Phys. Letts., B, **690,** 201.

V. R. Chitnis, J. K. Pendharkar, D. Bose, V. K. Agrawal, A. R. Rao and **Ranjeev Misra** (2009) X-ray variability of active galactic nuclei in the soft and hard x-ray bands, Ap. J., **698**, 1207.

V. K. Agrawal and **Ranjeev Misra** (2009) X-ray spectral evolution of the extragalactic Z source LMC X-2, MNRAS, **398,** 1352.

Andrzej A. Zdziarski, **Ranjeev Misra** and Marek Gierlinski (2010) Compton scattering as the explanation of the peculiar x-ray properties of Cyg X-3, MNRAS, **402**, 767.

K. P. Harikrishnan, **Ranjeev Misra** and *G. Ambika* (2009) Combined use of correlation dimension and entropy as discriminating measures for time series analysis, Comm. in Nonlinear Science & Numerical Simulation, **14**, 3608.

K. P. Harikrishnan, **Ranjeev Misra**, *G. Ambika* and R. E. Amritkar (2009) Computing the multifractal spectrum from time series : An algorithmic approach, CHAOS, **19**, 043129.

K. P. Harikrishnan, **Ranjeev Misra**, *G. Ambika* and R. E. Amritkar (2010) Parametric characterisation of a chaotic attractor using the two scale Cantor measure, Physica D, **239**, 420.

S. Shivaji, (including **J. V. Narlikar**), et.al., (2009) *Janibacter hoylei sp. nov., Bacillus isronensis sp. nov. and Bacillus aryabhattai sp. nov., isolated from cryotubes used for collecting air from the upper atmosphere*, Int. J. of Systematic and Evolutionary Microbiology, **59**, 2977.

P. Noterdaeme, C. Ledoux, **R. Srianand**, P. Petitjean and S. Lopez (2009) Diffuse molecular gas at high redshift. Detection of CO molecules and the 2175~AA dust feature at z = 1. 64, A & A, **503**, 765.

P. Noterdaeme, P. Petitjean, C. Ledoux and **R. Srianand** (2009) Evolution of the cosmological mass density of neutral gas from Sloan Digital Sky Survey II - Data Release 7, A &A, **505**, 1087.

J. S. Bagla, Girish Kulkarni and **T. Padmanabhan** (2009) Metal enrichment and reionization constraints on early star formation, MNRAS, **379**, 971.

Aseem Paranjape and **T. Padmanabhan (2009)** Radiation from collapsing shells, semiclassical backreaction and black hole formation. Phys. Rev. D, **80**, 044011.

T. Padmanabhan (2009) Entropy density of spacetime and gravity : A conceptual synthesis, Int. Jour. Mod. Phys. D, **18,** 2189.

T. Padmanabhan (2010) Thermodynamical aspects of gravity : New insights, *Reports in Progress of Physics*, **73**, 046901.

T. Padmanabhan (2010) Equipartition of energy in the horizon degrees of freedom and the emergence of gravity, Mod. Phys. Letts., A, **25**, 1129.

Hamsa Padmanabhan and **T. Padmanabhan** (2010) Aspects of electrostatics in a weak gravitational field, Gen. Rel. Grav., **42**, 1153.

T. Padmanabhan (2010) Surface Density of Spacetime Degrees of Freedom from Equipartition Law in theories of Gravity, Phys. Rev., D, **81,** 124040.

Harsha Raichur and B. Paul (2010) Effect of pulse profile variations on measurement of eccentricity in orbits of Cen X-3 and SMC X-1 MNRAS, **401**.

Harsha Raichur, B. Paul (2010) Apsidal motion in 4U 0115+63 and orbital parameters of 2S 1417-624 and V0332+53, MNRAS, **406**, 2663.

A. J. Castro-Tirado, (including **A. N. Ramaprakash**), et. al., (2009) Multi-wavelength observations of the GRB 080319B afterglow and the modeling constraints, A & A, **504**, 45.

Mudit K. Srivastava, **A. N. Ramaprakash**, **Mahesh P. Burse**, **Pravin A. Chordia**, **Kalpesh S. Chillal**, **Vilas B. Mestry**, **Hillol K. Das** and **Abhay A. Kohok** (2010) TELICS- A telescope instrument control system for small/ medium sized astronomical observatories, PASP, **121**, 111.

Mudit K. Srivastava, **Swapnil M. Prabhudesai** and **Shyam N. Tandon** (2009), Studying the imaging characteristics of Ultra Violet Imaging Telescope (UVIT) through numerical simulations, PSAP, **121**, 621.

Minu Joy, Arman Shafieloo, **Varun Sahni** and Alexei Starobinsky, (2009) Is a step in the primordial spectral index favoured by CMB data?, JCAP, **06**, 028.

Arman Shafieloo, **Varun Sahni** and Alexei Starobinsky (2009) Is cosmic acceleration slowing down?, Phys. Rev. D, **80**, 101301 (R)

Ujjaini Alam, **Varun Sahni** and Alexei Starobinsky (2009) Reconstructing cosmological matter perturbations using standard candles and rulers, Ap. J., **704**, 1086.

S. Samui, **R. Srianand** and **K. Subramanian** (2009) Understanding the redshift evolution of the luminosity functions of Lyman-α emitters, MNRAS, **398**, 2061.

S. Samui, **K. Subramanian** and **R. Srianand** (2009) Models of high redshift luminosity functions and galactic outflows : The dependence on halo mass function, New Astronomy, **14**, 591.

S. Samui, **K. Subramanian** and **R. Srianand** (2010) Cosmic ray driven outflows from high-redshift galaxies, MNRAS, **402**, 2778.

A. J. Fox, P. Petitjean, C. Ledoux and **R. Srianand** (2009) Studying hot gas using the ultraviolet : High ions in galactic halos, Ap & SS, **320**, 27.

A. J. Fox, J. X. Prochaska, C. Ledoux, P. Petitjean, A. M. Wolfe and **R. Srianand** (2009) Metal-enriched plasma in protogalactic halos. A survey of N V absorption in high-z damped and sub-damped Lyman-alpha systems, A & A, **503**, 731.

N. Gupta, **R. Srianand**, P. Petitjean, **P. Noterdaeme** and D. J. Saikia (2009) A complete sample of 21cm absorbers at z ~ 1. 3 : Giant Metrewave Radio Telescope survey using Mg~II systems, MNRAS, **398**, 201.

M. Vivek, **R. Srianand**, **P. Noterdaeme**, **V. Mohan** and *V. C. Kuriakose* (2009) SDSS J092712. 64+294344. 0 : Recoiling blackhole or merging galaxies ?, MNRAS, **400**, 6L.

P. Petitjean and **R. Srianand**, H. Chand, A. Ivanchik, **P. Noterdaeme** and N. Gupta (2009) Constraining fundamental constants of physics with quasar absorption line systems, SSRv, **148**, 289.

C. S. Stalin, P. Petitjean, **R. Srianand**, A. Fox, F. Copollani and A. Schwope (2010) Optical identification of XMM sources in the Canada-France-Hawaii telescope legacy survey, MNRAS, **401**, 294.

P. Noterdaeme, **R. Srianand** and **V. Mohan** (2010) Quasars Probing intermediate-redshift star-forming galaxies, MNRAS, **403**, 906.

Moumita Aich and **Tarun Souradeep** (2010) Statistical isotropy violation of the CMB brightness fluctuations, Phys. Rev. D, **81**, 083008.

Nidhi Joshi, *Sanjay Jhingan*, **Tarun Souradeep** and Amir Hajian (2010) Bipolar harmonic encoding of CMB correlation patterns, Phys. Rev. D, **81**.

Jan Hamann, Arman Shafieloo and **Tarun Souradeep** (2010) Features in the primordial power spectrum? A frequentist analysis, JC A P, **04**, 010.

P. K. Samal, R. Saha, J. Delabrouille, S. Prunet, P. Jain and **Tarun Souradeep** (2010) CMB polarization and temperature power spectra estimation using linear combination of WMAP 5-year maps Ap. J., **714**, 84.

S. Sridhar and **K. Subramanian** (2009) Shear dynamo problem : Quasilinear kinematic theory, Phys. Rev. E, **79**, 045305 (R).

T. R. Seshadri and **K. Subramanian** (2009) Cosmic microwave background bispectrum from primordial magnetic fields on large angular scales, Phys. Rev. Letts., **103**, 081303, 1.

S. Sridhar and **K. Subramanian** (2009) A non-perturbative quasilinear approach to the shear dynamo problem, Phys. Rev. E, **80**, 066315.

S. K. Sethi and **K. Subramanian** (2009) Primordial magnetic fields and the HI signal from the epoch of reionization, JCAP, **11**, 021.

A. W. Baggaley, C. F. Barenghi, A. Shukurov and **K. Subramanian** (2009) Reconnecting flux-rope dynamo, Phys. Rev. E, **80**, 055301 (R), 1.

K. Subramanian (2010) Magnetic fields in the early universe, Astronomische Nachrichten, **331**, No. 1, 110.

A. W. Baggaley, C. F. Barenghi, A. Shukurov and **K. Subramanian** (2010) Fluctuation dynamo based on magnetic reconnections, Astronomische Nachrichten, **331**, No. 1, 46.

Proceedings

Joydeep Bagchi, *Joe Jacob*, GopalKrishna, Norbert Werner, Nitin Wadnerkar, Jaydeep Belapure and A. C. Kumbharkhane (2009) *Diffuse bubble-like radio-halo emission in MRC 0116+111 : imprint of AGN feedback in distant cluster of galaxies*, Proceedings of "The Low-Frequency Radio Universe", Pune, India, ASP Conference Series 407, (Conference held during December 8 - 12, 2008), at National Centre for Radio Astrophysics (NCRA), TIFR, Pune, India. Edited by D. J. Saikia, D. A. Green, Y. Gupta, T. Venturi, Astronomical Society of the Pacific Conference series, **407**, 255B.

Joydeep Bagchi, Gopal Krishna, M. Krause, **C. Konar** and S. Joshi (2009), *A giant radio jet of very unusual polarization in a single-lobbed radio galaxy*, Proceedings of "The Low-Frequency Radio Universe ASP Conference Series, (Conference held during December 8 - 12, 2008), at National Centre for Radio Astrophysics (NCRA), TIFR, Pune, India. Edited by D. J. Saikia, D. A. Green, Y. Gupta, and T. Venturi, Astronomical Society of the Pacific Conference series, **407**, 200B.

Asoke K. Sen, **Ranjan Gupta** and Jeremie Lasue (2009) *Recent polarimetric observations of comet 67 P Churyumov-Gerasimenko' Anny-Chantal Levasseur-Regourd*, *Edith Hadamcik*, Icy Bodies of Solar System, Proc. of IAU Symp. No. 263, Ed : D. Lazzaro, et al. (check published reference)

A. Kamble, A. J. van der Horst, **D. Bhattacharya**, R. Wijers, C. H. Ishwara Chandra, L. Resmi, E. Rol, C. Kouveliotou and R. Strom (2009) *Five years of multi-frequency monitoring of GRB030329 afterglow using the GMRT and WSRT*, in The Low Frequency Radio Universe, ASP Conference Series, **407**, pp. 295.

L. Resmi and **D. Bhattacharya** (2009) *Hard electron distribution in gamma ray burst afterglows*, in GAMMA-RAY BURST : Sixth Huntsville Symposium, AIP Conference Proceedings, **1133,** 241**.**

S. B. Pandey, A. J. Castro-Tirado, A. P. Kamble, **D. Bhattacharya**, M. Jelinek, J. Gorosabel, A. de Ugarte Posigo, R. Oreiro, M. Bremer and A. Pozanenko (2009) *Observations of afterglow of GRB 080319B and the modeling constraints*, in GAMMA-RAY BURST : Sixth Huntsville Symposium, AIP Conference Proceedings, **1133**, 238.

Atish Kamble, A. J. van der Horst, **D. Bhattacharya**, Ralph, Wijers, C. H. Ishwara-Chandra, L. Resmi, E. Rol, E., C. Kouveliotou and R. Strom (2009) *Five years of multi-frequency monitoring of GRB030329 afterglow using the GMRT and WSRT*, in GAMMA-RAY BURST : Sixth Huntsville Symposium, AIP Conference Proceedings, 1133, 169.

Burbidge, Geoffrey and **J. V. Narlikar** (2009) *Critical reactions to the hot big bang interpretation*, Finding the Big Bang, Eds. P. James E. Peebles, Lyman A. Page, Jr. and R. Bruce Partridge (Cambridge University Press), 267

Jayant V. Narlikar and Rajesh K. Kochhar (2009) *Post-Independence Indian achievements in astronomy*, Science in India, Ed. Jayant V. Narlikar, (PHISPC and VIVA), **287**.
J. V. Narlikar (2009) *Alternative cosmologies*, Cosmology and Gravitation : XIII Brazilian School on Cosmology and Gravitation, Eds. M. Novello and S. E. Perez Bergliaffa, (AIP Conference Proceedings), **1132**, 1.

Narlikar, J. V. (2010) *Einstein and cosmology*, Remembering Einstein, Ed. B. V. Sreekantan, (Oxford University Press), 35.

Luigi Iapichino, Jens C. Niemeyer, **Surajit Paul** and Wolfram Schmidt (2010) *Turbulence Modeling and the Physics of the Intra-Cluster Medium*, in High Performance Computing in Science and Engineering, SpringerLink, **383-394.**

Ghanashyam Date and **Tarun Souradeep** (2008) Proc. of the Sixth International Conference on Gravitation and Cosmology (ICGC 2007), Journal of Physics : Conference Series, 140, 011001.

S. Rasouli, **A. N. Ramaprakash**, **H. K. Das**, et al., (2009) *Two-channel wavefront sensor arrangement employing moire deflectometry*, in Optics in Atmospheric Propagation and Adaptive Systems XII, edited by Anton Kohnle, Karin Stein, John D. Gonglewski, SPIE Proceedings, 7476.

Circulars and Telegrams

D. Bhattacharya, **V. Mohan**, **A. N. Ramaprakash**, **C. Rajarshi** and **K. Misra** (2010) GRB 100206A : Optical limit, GCN Circular No. 10380.

A. Kamble, S. Pal, **D. Bhattacharya**, R. Wijers and C. H. Ishwara Chandra (2009) SN2007bg : GMRT radio observations, The Astronomers' Telegram, No. 2133.

A. Kamble, S. Pal, A. J. van der Horst, **D. Bhattacharya**, R. Wijers, C. H. Ishwara-Chandra and E. Rol (2009) GMRT observation of GRB 090424 afterglow, GCN Circular No. 9484.

Books (Authored/ Edited)

J. V. Narlikar (2009) Science in India, PHISPC, New Delhi and VIVA Books, New Delhi.

J. V. Narlikar (2010) An Introduction to Relativity, Cambridge University Press, Cambridge.

Padmanabhan, T. (2010) Gravitation : Foundations and Frontiers, Cambridge University Press, Cambridge.

(b) By Visiting Associates

Journals

G. Ambika and R. E. Amritkar (2009) Anticipatory synchronization with variable time delay and reset, Phys. Rev. E, **79**, 056206.

S. Chakraborty and T. Bandyopadhyay (2009) Cosmological solution in the brane with Gauss-Bonnet gravity in the bulk, Mod. Phys. Lett. A.. **24**, 1915.

S. Chakraborty and T. Bandyopadhyay (2009) Thermodynamics of the universe with modified chaplygin gas, Mod. Phys. Lett. A., **24**, 2377.

T. Bandyopadhyay, A. Baveja and **S. Chakraborty** (2009) Stability analysis of thin shell wormholes supported by modified Chaplygin gas, Int. J. of Mod., Phys. D **18**, 1977.

T. Bandyopadhyay and **S. Chakraborty** (2009) Cosmic no-hair theorem in brane scenarios : Constraint on bulk matter, Gen. Rel. and Grav., **41**, 2461.

T. Bandyopadhyay and **S. Chakraborty** (2009) Thin shell wormholes in Einstein-Yang-Mills-Gauss-Bonnet theory, Class. and Quant. Grav., **26**, 085005.

Nairwita Mazumder and **S. Chakraborty** (2009) Validity of the Generalized Second Law of Thermodynamics of the Universe bounded by the Event Horizon in Holographic Dark Energy Model, Gen. Rel. and Grav., **42**, 813.

Nairwita Mazumder and **S. Chakraborty** (2009) Does the validity of the first law of thermodynamics imply that the generalized second law of thermodynamics of the universe is bounded by the event horizon?, Class. and Quant. Grav. **26**, 195016

Ritabrata Biswas and **S. Chakraborty** (2009) The geometry of the higher dimensional black hole thermodynamics in Einstein-Gauss-Bonnet Theory, Gen. Rel. and Grav., **42**, 1311.

Ritabrata Biswas and **S. Chakraborty** (2010) Thermodynamics of black holes in Einstein-Maxwell-Gauss-Bonnet Theory, Int. J. of Theor. Phys., **49**, 152.

T. Bandyopadhyay and **S. Chakraborty** (2010) Energy conditions, cosmological solutions and cosmic hair conjecture in Gauss-Bonnet gravity, Int. J. of Theor. Phys., **48**, 1369.

Ritabrata Biswas and **S. Chakraborty** (2010) Black holes in the Einstein-Gauss-Bonnet theory and the geometry of their thermodynamics-II, Ap and SS, **326**, 39.

Sabyasachi Bhattacharya, Arindam Gupta and **Asis Kumar Chattopadhyay** (2009) Effect of migration on population growth under dynamical system, J. Applied Probability and Statistics, **4 (2),** 239.

G. J. Babu, **Tanuka Chattopadhyay, Asis Kumar Chattopadhyay** and Saptarshi Mandal (2009) A horizontal branch morphology of globular clusters : A multivariate statistical analysis, Ap. J., **700**, 1768.

Asis Kumar Chattopadhyay, Tanuka Chattopadhyay, Emmanuel Davoust, Saptrashi Mondal and Margarita Sharina (2009) Study of NGC 5128 Globular Clusters under Multivariate Statistical Paradigm, Astrophysical Journal, **705**, 1533.

Mahadevappa Naganathappa and **Ajay Chaudhari** (2010) Absorption and vibrational spectra of methylamine and its ions using quantum chemical methods, Adv. Space Res. **45**, 521.

H. S. Das, A. Suklabaidya, S. Datta Majumder and **A. K. Sen**, (2010) Aggregate dust model to study the polarization properties of comet C/1996 B2 Hyakutake. Res. Astron. and Astrophy., **10**, 355.

S. Das and **U. Debnath** (2009) Statefinder description of a cosmological model based on a mixture of five fluids**,** Ap and SS, **324**, 61.

S. Chattopadhyay and **U. Debnath** (2010) Interaction between phantom field and modified Chaplygin gas**,** Ap and SS, **326**, 155.

P. Khatau and **U. Debnath** (2010) Role of Chameleon field in accelerating universe, Ap and SS, **326,** 53.

S. Jhingan and **Sushant G. Ghosh** (2010) Inhomogeneous dust collapse in 5D Einstein-Gauss-Bonnet gravity, Phys. Rev. D, **81**, 024010.

Sarbari Guha and **Subenoy Chakraborty** (2010) Brane cosmology and motion of test particles in five-dimensional warped product spacetimes, Gen. Rel. Grav., **42**, 7, 1739.

Ng. Ibohal (2009) Non-stationary de Sitter cosmological models, Int, J. of Mod. Phys. D, **18**, No. 5, 853.

Ablu Meitel, K. Jugindro Singh, T. Ibungochouba Singh and **Ng. Ibohal** (2010) Phase transition in the Reissner – Nordstrom black hole, Ap and SS, **327**, No. 2, 67.

Naseer Iqbal, M. N. Vahia, A. Ahmad and T. Masood (2009) The prehistoric meteor shower recorded on a palaeolithic rock, NRIAG J of Astron. and Astrop. **38**, 469.

M. S. Khan, **Naseer Iqbal** and F. Ahmad (2009) Thermodynamic fluctuation theory and gravitational galaxy clustering, Electronic J. of Theor. Physics, **21,** 139.

M. S. Khan, **Naseer Iqbal** and F. Ahmad (2009) Critical phenomena and gravitational galaxy clustering, NRIAG J. of Astron. and Astrophys. **39,** 477.

Shubhra Tiwari, **S. N. A. Jaaffrey**, Rizwan S. Khan, Sushil K. Gandhi and Santvana Bapna (2010) Timing and spectral studies of pulsar EXO2030+375, Chin. Phys. Letts., **27**, No. 2 029701.

Lokesh Bharti, Chandan Joshi, **S. N. A. Jaaffrey** and Rajmal Jain (2009) Spectropolarimetry of umbral fine structures from Hinode : evidence for magneto convection, MNRAS, **393,** 65.

S. N. A. Jaaffrey and Shubhra Tiwari (2009) Secondary x-ray environment in the lower atmosphere of the earth during monsoon season over Udaipur city (India) in July – September 2006, Chin. Phys. Letts., **26**, No. 8, 089201.

S. Jhingan and **S. G. Ghosh,** (2010) Collapse in Einstein Gauss Bonnet gravity, Phys. Rev. D, **81,** 024010.

J. D. Meiring, J. T. Lauroesch, V. P. Kulkarni, C. Peroux, **Pushpa Khare** and A. York (2009) A MIKE + UVES survey of Sub-Damped Lyman-alpha systems at z < 1. 5, D. G., MNRAS, **397,** 2037.

C. P. Jisha, **V. C. Kuriakose** and K. Porsezian (2009) Variational method in soliton theory, Eur. Phys. J. Special Topics, **173**, 341.

Nijo Varghese and **V. C. Kuriakose** (2009) Quasinormal modes of Reissner-Nordstrom black hole surrounded by quintessence, Gen. Rel. Grav. **41**, 1249.

Sini R. and **V. C. Kuriakose** (2009) Quasinormal modes of RN black hole space time with cosmic string in Dirac field, Mod. Phys. Lett. A, **24**, 2025.

T. Uthayakumar, C. P. Jisha, K. Porsezian and **V. C. Kuriakose** (2009) Switching dynamics of a two-dimensional nonlinear directional coupler in a Photopolymer, J. Opt. **12**, 015204.

Sini R., Nijo Varghese and **V. C. Kuriakose** (2010) Effect of cosmic string in spherically symmetric black hole on Dirac perturbation, Mod. Phys. Lett. A, **25**, 111.

Manzoor A. Malik, Farooq Ahmad, Shakeel Ahmad and Sajad Masood (2009) Statistical mechanics of galaxy clustering for a two-component system : Effect of extended nature of galaxies, Int. J. Mod. Phys. D, **18**, No. 6, 1.

Pradip Mukherjee and **Anirban Saha** (2009) Gauge invariances vis-s-vis diffeomorphisms in second order metric gravity, Int. J. Mod. Phys. A**, 24**, 4305.

Pradip Mukherjee and Saurav Samanta (2009) Topics in Non-commutative geometry inspired physics by Rabin Banerjee, Subir Ghosh, Found. Phys**. 39,** 1297.

Rabin Banerjee, Sunandan Gangopadhyay, **Pradip Mukherjee** and Debraj Roy (2010) Symmetries of topological gravity with torsion in the Hamiltonian and Lagrangian formalisms, JHEP, **02,** 075.

K. K. Nandi, I. R. Kizirgulov, O. V. Mikolaychuk, N. P. Mikolaychuk and A. A. Potapov (2009) Quantum phase shift in Chern-Simons modified gravity, Phys. Rev. D, **79**, 083006.

K. K. Nandi, A. I. Filippov, **F. Rahaman, Saibal Ray, A. A. Usmani,** M. Kalam and A. DeBenedictis (2009) Features of galactic halo in a brane world model and observational constraints, MNRAS, **399**, 2079.

K. K. Nandi, Y. Z. Zhang, R. G. Cai and A. Panchenko (2009) Energetics in condensate star and wormholes, Phys. Rev. D, **79**, 024011.

A. Palit, A. Panchenko, N. G. Migranov, and **K. K. Nandi** (2009) Stability of circular orbits in general relativity : A phase space analysis, Int. J. Theor. Phys., **48**, 1271.

A. Bhadra and **K. K. Nandi** (2010) Gravitational time advancement and its possible detection, Gen. Rel, Grav. **42**, 293.

P. Thakur, S. Ghose and **B. C. Paul** (2009) Modified Chaplygin gas and constraints on its B parameter from CDM and UDME Cosmological models, MNRAS, **397**, 1935.

B. C. Paul, P. S. Debnath and S. Ghose (2009) Accelerating universe in modified theories of gravity, Phys. Rev. D**, 79**, 083534.

B. C. Paul and S. Ghose (2010) Emergent Universe Scenario in the Einstein-Gauss-Bonnet Gravity with dilaton, Gen. Rel. Grav., **42**, 795.

P. K. Chattopadhyay and **B. C. Paul** (2010) Relativistic star solutions in higher dimensional pseudo-spheroidal spacetime, Pramana, J. of Phys., **74**, 513.

Ninan Sajeeth Philip (2009) What is there in a training sample?, 2009 World Conference on Nature and Biologically Inspired Computing (NaBIC-2009), IEEE, ISBN : 978-1-4244-5612-3.

F. Rahaman, **Saibal Ray**, M. Kalam and M. Sarker (2009) Do Solar system tests permit higher dimensional general relativity? Int. J. Theor. Phys., **48**, 3124.

F. Rahaman, Mubasher Jamil and Mehedi Kalam (2010) On the role of pressure anisotropy for relativistic stars admitting conformal motion, Ap and SS., **325,** 137.

M. Jamil and **F. Rahaman** (2009) On the resolution of cosmic coincidence problem and phantom crossing with triple interacting fluids, Eur. Phys. J. C, **64**, 97.

F. Rahaman, M. Kalam and K. A. Rahman (2009) Wormholes supported by scalar fields with negative kinetic energy, Int. J. Mod. Phys. A, **24,** 5007.

F. Rahaman, M. Kalam and K. A. Rahman (2009) Conical thin shell wormhole from global monopole : A Theoretical construction, Acta Phys. Polon. B, **40**, 1575
F. Rahaman, M. Jamil, A. Ghosh and K. Chakraborty (2010) On generating some known black hole solutions, Mod. Phys. Lett. A, **25**, 835.

Rakesh K. Rai and **Shantanu Rastogi** (2010) Scattering and extinction properties of nanodiamonds, MNRAS, **401**, 2772.

U. Mukhopadhyay, P. C. Ray, **Saibal Ray** and S. B. Dutta Choudhury (2009) Generalized model for Λ-dark energy, Int. J. Mod. Phys. D, **18,** 389.

Saibal Ray, **F. Rahaman** and U. Mukhopadhyay (2009) Scenarios of cosmic string with a variable cosmological constant, Int. J. Mod. Phys. D, **18,** 781.

Saibal Ray, P. C. Ray, M. Khlopov, P. P. Ghosh, U. Mukhopadhyay and P. Chowdhury (2009) Scenario of inflationary cosmology from the phenomenological Λ models, Int. J. Theor. Phys. **48,** 2499.

Anirban Saha and Sunandan Gangopadhyay (2009) Non-commutative quantum mechanics of a test particle under linearized gravitational waves, Phys. Lett. B, **681,** 96.

Sandeep Sahijpal and G. Gupta (2009) The plausible source (s) of ^{26}Al in the early solar system : A massive star or the x-wind irradiation scenario? Meteoritics and Planetary Science J. **44**, 879.

Huss Gary, B. S. Meyer, G. Srinivasan, J. N. Goswami and **S. Sahijpal** (2009) Stellar sources of the short-lived nuclides in the early solar system, Geochim. Cosmochim. Acta. **73**, 4922.

M. C. Liu, K. D. McKeegan, J. N. Goswami, K. K. Marhas, **S. Sahijpal**, T. R. Ireland and A. M. Davis (2009) Isotopic records in CM Hibonites : Implications for timescales of reservoir mixing in the solar nebula. Geochim. Cosmochim. Acta **73,** 5051.

D. Ward-Thompson, **A. K. Sen**, J. M. Kirk and D. Nutter (2009), Optical and sub-millimetre observations of Bok globules – tracing the magnetic field from low to high density, MNRAS, **398,** 394.

Sukanta Deb, S. K. Tiwari, **Harinder P. Singh**, **T. R. Seshadri** and U. S. Chaubey (2009) Photometry of the delta Scuti star HD 40372, BASI, **37**, 109.

T. R. Seshadri (2009) Learning about the Universe through cosmic mMicrowave background radiation, Current Science, **97**, 858.

S. Deb and **H. P. Singh** (2010) Physical parameters of the Small magellanic cloud RR Lyrae stars and the distance scale, MNRAS, **402**, 691.

S. Deb and **H. P. Singh** (2009) Light curve analysis of variable stars using Fourier decomposition and principal component analysis. A&A, **507**, 1729.

V. Suyal, A. Prasad and **H. P. Singh** (2009) Nonlinear time series analysis of sunspot data, Solar Physics**, 260**, 441.

Proceedings :

Chandan Joshi, Lokesh Bharti and **S. N. A. Jaaffrey** (2007) A high resolution study of umbral flashes and running perumbral waves using Hinode observations, Conference proceeding XII European Solar Physics meeting, page no. 227.

R. S. Goncalves, J. S. Alcaniz, A. Dev and **Deepak Jain** (2009) Constraining dark matter-energy interaction with gas mass fraction in galaxy clusters, Joint Discussion 9, IAU General Assembly, Rio de Janeiro, Brazil, Eds. : P. Molaro and E. Vangioni, Mem. S. A. It, 80, 921.

Manzoor A. Malik (2009**)** Statistical mechanics of the cosmological many-body problem, IMFP Proceedings of the American Institute of Physics, **1150**, 252.

H. P. Singh, P. S. Pal, M. P. Srivastava and K. L. Chan (2009) 3-D Simulation of penetrative convection with rotation, ASP Conf. Ser. 404, 283.

Books :

Suresh Chandra (2009) Classical Mechanics, Narosa Publishing House Pvt. Ltd., New Delhi and Alpha Science International Ltd., Oxford, UK.

Suresh Chandra (2009) Molecular Spectroscopy, Narosa Publishing House Pvt. Ltd., New Delhi and Alpha Science International Ltd., Oxford, UK.

Nagendra Kumar and Rakesh Kumar (2010) Partial Differential Equations with Numerical Solutions, Anamaya Publishers, New Delhi.

Supervision of Thesis :

G. Ambika (2009) Studies on stability, synchronization and scaling behaviour in coupled nonlinear systems, Mahatma Gandhi University, Kottayam, Ph.D. thesis of Ambika K.

Asis Kumar Chattopadhyay (2009) Problems related to social processes- A statistical study, Calcutta University, Kolkata, Ph.D. thesis of Arindam Gupta.

S. N. A. Jaaffrey (2009) Modeling and study of activity of sunspots and their periodicity, Mohanlal Sukhadia University, Udaipur, Ph.D. thesis of Chandan Joshi.

B. C. Paul (2010) Cosmological models of the early universe, North Bengal University, West Bengal, Ph.D. Thesis of Dilip Paul.

T. R. Seshadri (2009) Theoretical study of dark energy parameters in cosmology, University of Delhi, Ph.D. Thesis of Sanil Unnikrishnan.

T. R. Seshadri (2009) Nature of clustering of large-scale structures, University of Delhi, Ph.D. thesis of Jaswant Kumar.

H. P. Singh (2010), Complexity measures of chaotic time series and their application, University of Delhi, Ph.D. thesis of Kopal Gupta.

(V) PEDAGOGICAL ACTIVITIES

(a) IUCAA-NCRA Graduate School

Dipankar Bhattacharya
Quantum and Statistical Mechanics II

Sanjeev Dhurandhar
Methods of Mathematical Physics I

Gulab Chand Dewangan
Electrodynamics and Radiative Processes I

Ranjeev Misra
Electrodynamics and Radiative Processes II

T. Padmanabhan
Topical course on Advanced Topics in General Relativity (February 2010)

Maulik Parikh
Quantum and Statistical Mechanics I

A. N. Ramaprakash
Interstellar Medium

Swara Ravindranath
Galaxies : Structure, Dynamics and Evolution

Varun Sahni
Extragalactic Astronomy I

R. Srianand
Introduction to Astronomy and Astrophysics I

Tarun Souradeep
Methods of Mathematical Physics II

(b) University of Pune M. Sc. (Physics and Space Science)

Joydeep Bagchi
Experiments and Laboratory for Astronomy and Astrophysics III and IV semesters (3 experiments, 12 sessions in IUCAA-NCRA Radio-Physics Laboratory)

Ranjan Gupta
Astronomy and Astrophysics I (Theory 10 lectures) and Laboratory for III and IV semester courses (10 sessions and night experiments)

K. Subramanian
Astronomy and Astrophysics I (about 18 lectures)
Astronomy and Astrophysics II (about 17 lectures)

(c) Supervision of Projects

Joydeep Bagchi

Nishikant Jadhav (Department of Electronics and Telecommunication, Government College of Engineering, Pune) *Construction of a 12-element quad-Yagi (Quagi) antenna at 408 MHz for radio astronomy applications*
M. Tech. Project.

(Jointly with Surajit Paul)
Amol Deshmukh, Amol Ratnaparke, Sameep Chandel, Mohit Tanga, Chandan Kumar, Prashant Mishra :
(For Integrated M. Sc. students from IISER Mohali)
Radio Astronomy and Physics Experiments.

Bhaswati Bhattacharyya

Aswathi Ganesh (M. Sc. 2nd year, Calicut University, Kozhikode)
Multi frequency study of sub pulse drifting and nulling properties for PSR B1819-22.

Sunil Kumar Pilakkal (M. Sc. 2nd year Calicut University (March 2010)
Investigation of anomalous drifting mode and the interactions between the nulling and drifting for PSR B1819 - 22

Dipankar Bhattacharya

Subhasis Chandra (University of Pune, M. Sc.)
Long-term evolution of gamma ray burst afterglows.

Gulab Chand Dewangan

Sibasish Laha (IUCAA)
Warm absorption and emission from Seyfert 1 galaxies

Sanjeev Dhurandhar

Maryam Arabsalmani
(IUCAA -NCRA Graduate School)
Gravitational waves.

Harsha Raichur

Sunil Kumar, Aswathi Ganesh (M. Sc. 2nd year, Calicut University, Kozhikode)
Compact stars

Fayas Ahmed Najar
(University of Kashmir)
Long term spectral evolution of Low Mass X-ray binaries

Ajit Kembhavi

Bharat Warule and Rakesh Pardeshi
(University of Pune, M. Sc.)
Bisector regression line with m easurement error and intrinsic scatter for fundamental planes.
Santosh Jagade
(Ferguson College, Pune, M. Sc.)
JAX - web services for VOStat.

Abhishek Dey
(Abasaheb Garware College, Pune, M. Sc.)
JAX - web services for VOStat.

Devdeep Roy Choudhury
(Indian School of Mines University, Dhanbad)
Development of SAMP Driver.

Vijay Mohan

Anju M. and Fini E. Prasad (M. G. University, Kottayam, M. Sc.)
Image processing and stellar photometry.

Ali Reza
(Zanjan University, M. Sc.)
Crowded field stellar photometry

Ranjeev Misra

Vikram Khaire
(University of Pune, M. Sc.)
Astrophysical Jets.

J. V. Narlikar

Summer School Students' Programme
Foucault Pendulum.

ISRO Cryosampler Balloon Project

A. N. Ramaprakash

M. T. Salpure (Universityof Pune, M. Sc.)
Multi-interface board assembly and testing.

B. U. Shinde (University of Pune, M. Sc.)
Multi-interface board assembly and testing.

Swara Ravindranath

Rishikesh Pandit,
(Ferguson College, Pune, B. Sc.)
HII region photometry of circumnuclear starbursts in NGC 6951.

Sandesh Kulkarni,
(University of Pune, M. Sc.)
Study of evolution of morphology of high redshift galaxies.

Nimisha Baranwal
(BITS-Pilani, B. E. VSP)
Binary black holes.

R. Srianand

Hadi Rahmani
(IUCAA-NCRA Graduate School)
Probing the reionization history using high-z QSOs.

(d) Supervision of Ph.D. Thesis

Ajit Kembhavi (Guide)
By Susmita Chakravorty
Physics of Radiation from AGN

Ranjan Gupta (Guide)
By Hillol K. Das
Astrophysical applications of light scattering phenomenon by dust

Ajit Kembhavi (Guide)
By Abhishek Rawat
Studying the properties of intermediate redshift galaxies using large surveys

K. Subramanian (Guide)
R. Srianand (Co-Guide)
By Saumyadip Samui
Physics of structure formation and intergalactic medium

T. Padmanabhan (Guide)
By Sudipta Sarkar
Quantum effects and thermodynamics of horizons in strong gravitational field

Varun Sahni (Guide)
By Arman Shafieloo
Confronting cosmological models with observations

K. Subramanian (Guide)
By Sharanya Sur
Origin and Evolution of Cosmic Magnetic Fields

(e) Pedagogical Articles in Physics

T. Padmanabhan

Lagrange has (more than) a point!, Resonance, **14**, 318-327, 2009.

Why does an accelerate charge radiate?, Resonance, **14**, 499-507, 2009.

Perturbing Coulomb to avoid accidents!, Resonance, **14**, 622-629, 2009.

Random walk through random walks - I, Resonance, **14**, 638-649, 2009.

Random walk through random walks - II, Resonance, **14**, 799-806, 2009.

Extreme physics, Resonance, **14**, 907-915, 2009.

Wigner's function and semi-classical limit, Resonance, **14**, 934-943, 2009.

Real effects from imaginary time, Resonance, **14**, 1060-1070, 2009.

Kepler and his problem, Resonance, **14**, 1144-1152, 2009.

(VI) IUCAA SEMINARS and COLLOQUIA

08.04.2009, Satish Chand Abbi on *The Bosonic effects in laser Raman spectroscopy.*

15.04.2009 Sergey V. Chervon on *Exact inflation and calculation of cosmological parameters.*

22.04.2009 J. Maharana on *S-duality and string cosmology.*

30.04.2009 Sourav Sur on *Crossing the cosmological constant barrier with multifield K-essence/quintessence.*

11.06.2009, Harsha Raichur on *Determining the orbital parameters of Be-star x-ray binaries.*

23.06.2009, Siddharth Malu on *Fizeau beam combination for CMB polarization instruments.*

24.06.2009, Kuntal Misra on *Dust and gas in the local environment of gamma ray bursts*

24.6.2009, Pasquier Noterdaeme on *Quasars probing galaxies.*

25.6.2009, Rajdeep M. Chatterjee on *Radiation from a collimated relativistics fireball.*

25.6.2009, Vikram Kisan Khaire on *Astrophysical turbulence.*

25.6.2009, Nimisha Kumari on *Influence of black holes on the core of galaxies.*

25.6.2009, Siddartha S. Verma on *Measurement of focal ratio degradation in optical fibres used in astronomy.*

25.6.2009, Radouane Gannouji on *Dark energy and modified gravity.*

29.6.2009, Kinjal Banerjee on Looking for Casimir effect in polymer quantization.

17.08.2009, Edith Hadamcik on Polarization imaging of cometary comae dust.

17.09.2009, Smriti Mahajan on *Star formation and environment of galaxies.*

01.10.200, 9 Donald Lynden-Bell on *Is all motion relative?*

02.10.2009, Maulik Parikh on *Fun with topology and relativity.*

23.10.2009, C. H. Ishwara-Chandra on *A deep search for high-redshift radio galaxies.*

12.11.2009, Maryam Arabsalmani on *Gravitational waves.*

12.11.2009, Golam Hossain on *Driving cosmic inflation on a bumpy road.*

19.11.2009, Soumen Basak on *Simulating weak lensing of CMB maps*

08.12.2009, Hamsa Padmanabhan on *Aspects of electrostatics in a weak gravitational field.*

10.12.2009, Jaswant K. Yadav on *Fractal dimension as a quantifier of LSS clustering*.

31.12.2009, Pradip Mukherjee on *Symmetries of the general topologically massive gravity in the Hamiltonian and Lagrangian formalisms.*

05.01.2010, Prateek Sharma on *Dynamics and energetics of plasma in the cores of galaxy clusters.*

07.01.2010, Philippe Prugniel on *The star formation at z = 1 in nearby galaxies.*

15.01.2010, Norbert Werner on *Feedback under the microscope : A close-up view of the AGN-ICM interaction in M87.*

18.01.2010, Mudit K. Srivastava on *Imaging characteristics of ultra violet imaging telescope (UVIT) through numerical simulations*.

19.01.2010, Durgesh Tripathi on *Dynamics of the solar corona.*

20.01.2010, Aurora Simionescu on *Large-scale motions in the ICM of galaxy clusters from an x-ray, numerical and radio perspective.*

20.01.2010, Michal Ostrowski on *A review of H. E. S. S. results.*

04.02.2010, D. B. Vaidya on *Composite interstellar grains.*

23.02.2010, Atul Deep on *Use of AO PSF models to study resolved stellar populations with MICADO.*

26.02.2010, Danielle Alloin on *Extremely massive and young star clusters at the LIR in barred galaxies : Formation process.*

11.03.2010, Amit Roy on *Renaissance in nuclear sciences.*

22.03.2010, Lokesh C. Tribedi on *Highly charged ions to probe atoms, molecules and clusters : Present and future.*

Colloquia

06.07.2009, Ronojoy Adhikari on *Markov chains for the indus script.*

19.10.2009 Gerry Skinner on *The swift / bat hard x-ray survey*.

26.11.2009, Nobuyuki Kanda on *Japanese future gravitational wave projects on and off earth!*

19.01.2010, Devendra Lal on *Direct measurements of solar activity in the past 35, 000 years*.

02.02.2010, Wei-Tou Ni on *Gravitational wave detectors in space and the detectability of primordial inflationary gravitational waves*.

09.02.2010, Sanjay Puri on *Pattern formation in the kinetics of phase transitions.*

(VII) TALKS AT IUCAA WORKSHOPS OR AT OTHER INSTITUTIONS

(a) Seminars, Colloquia and Lectures

Joydeep Bagchi

Acceleration of cosmic rays at the structure formation Shocks, The Indo-French meeting, NCRA, Pune, December 2009.

Clusters of galaxies, IUCAA Vacation Students' Programme, VSRP and Refresher Course, May – June 2009 (2 lectures).

Galaxy clusters and groups, IUCAA-NCRA Radio Astronomy Winter School 2009 (2 Lectures and 3 Experiments, in collaboration with B. C. Joshi, NCRA).

Observing non-thermal radio emission from intergalactic Shocks, ASI XXVII Meeting, IIA Bangalore, 2009.

Amateur radio astronomy in IYA 2009, ASI sponsored Pro-Am Collaboration meeting, Jawaharlal Nehru Planetarium, Bangalore, 2009.

Bhaswati Bhattacharyya

Study of pulsars with Fermi-LAT, COSPAR Capacity Building, Workshop on Data Analysis of the Fermi Gamma-ray Space telescope, RRI, Bangalore, February 2010.

Single pulse studies of wide profile drifting pulsars - a probe of pulsar magnetospheres, RRI, Bangalore, November, 2009.

Single pulse studies of wide profile drifting pulsars - a probe of pulsar magnetospheres, PhD thesis defense, IISc, Bangalore, November 2009.

Dipankar Bhattacharya

Survey of astronomy (2 Lectures) IUCAA Vacation Students' Programme, May 11- 12.

Explosions in the cosmos, North Bengal University, Siliguri, May 22.

Astronomy in x-rays, IRC, North Bengal University, Siliguri, May 23.

ASTROSAT, IUCAA Vacation Students' Programme, May 29.

Introduction to astronomy, Orientation workshop for ASTROSAT data products team, IUCAA, Pune, June 29.

Multiwavelength astronomy, Orientation workshop for ASTROSAT data products team, IUCAA, Pune, June 29..

Compact objects with ASTROSAT, Orientation workshop for ASTROSAT data products team, IUCAA, Pune, June 30.

ASTROSAT as a timing instrument, the International Astronomical Union General Assembly, Rio de Janeiro, August 5.

Gamma ray bursts, Workshop on Observational Astronomy, Indian Statistical Institute, Kolkata, August 18.

Pulsars, Workshop on Observational Astronomy, Indian Statistical Institute, Kolkata, August 18.

Coded mask imaging with ASTROSAT, the International Conference on High Performance Computing in Observational Astronomy - Requirements and Challenges, IUCAA, Pune, October 14.

Cosmic explosions, Radio Astronomy Winter School, IUCAA-NCRA, December 28.

Gamma ray bursts : The brightest explosions in the universe, Workshop on Astrophysics and Cosmology, IRC, Kolkata University, January 13.

Magnetic fields of neutron stars : from Gigagauss to Petagauss, Workshop on Astrophysics and Cosmology, IRC, Kolkata University, January 14.

Probing neutron stars with ASTROSAT, the ISSI team meeting on Strong Gravitational Field and Ultra-Dense Matter in Neutron Stars, ISSI, Berne, January 21.

ASTROSAT - A forthcoming Indian Satellite Mission for multiwavelength astronomy, Observatorio Astronomico di Brera, Milan, Italy, January 26.

Radiative processes, in COSPAR Capacity Building Workshop on Fermi Data Analysis, RRI, Bangalore, February 9.

Pulsars, in COSPAR Capacity Building Workshop on Fermi Data Analysis, RRI, Bangalore, February 10.

Supernova remnants, in COSPAR Capacity Building workshop on Fermi Data Analysis, RRI, Bangalore, February 11.

Naresh Dadhich

Basic forces of nature, IUCAA Resource Centre at University of Calcutta, Kolkata, April 21.

Universalization as a physical guiding principle, Instituto de Fisica Teorica, Universidade Estadual Paulista, Brazil, during May 7- 24.

Lovelock gravitational dynamics, a talk delivered during an International Conference on "Classical and Quantum Gravity" at the Pennsylvania State University, U. S. A. during June 1- 6.

Lovelock gravitational dynamics, a talk delivered during the XXI Rencontres de Blois Conference on "Windows on the Universe" at the Chateau Royal de Blois (Loire Valley), France during June 21 -26.

Lovelock gravitational dynamics, Institute of Cosmology and Gravitation, University of Portsmouth, U. K. during June 26 – July 12.

Black hole from pure curvature, a talk delivered at the Marcel Grossmann Meeting (MG 12) at UNESCO, Paris during July 12 - 18.

Lovelock gravitational dynamics, Institute of Theoretical Physics, Geneva University, Switzerland, during July 18 - 30.

Hillol K. Das

IUCAA Instrumentation - Past, present and future, First IUCAA Reunion meeting, IUCAA, August 13.

Gulab Chand Dewangan

X-ray investigations of active galactic nuclei, Pt. Ravishankar Shukla University, Raipur July 17.

Active galactic nuclei : Central engine and the x-ray emission, Advanced workshop in Astronomy : Observations and Theory, North Bengal University, during April 5-9.

X-ray spectroscopy, Advanced Workshop in Astronomy : Observations and Theory, North Bengal University, Siliguri, during April 5 -9.

Sanjeev Dhurandhar

Highlights in gravitational wave research at IUCAA, IUCAA Reunion Meeting, IUCAA, August 11.

Coherent versus coincidence search for gravitational waves from inspiraling binaries, Galileo Xu Guangqi Meeting, Shanghai, China, October 26.

Gravitational wave experiments : Report from India, Australian International Gravitational Wave Observatory Workshop, Perth, Australia, February 22.

Time-delay interferometry for LISA, Australian International Gravitational wave Observatory workshop, Perth, Australia, February 24.

Time-delay interferometry for LISA : Recent developments, Albert Einstein Institute, Potsdam, Germany, August 3.

Gravitational waves : A challenge, HRI, Allahabad, December 9.

Second generation TDI for LISA, Osaka City University, Osaka, Japan, March 9.

Ranjan Gupta

Interstellar dust and its modeling, Department of Physics and Astronomy, University of Wisconsin, Oshkosh, USA, Septmber 28.

Artificial neural network — New applications in astronomy, STSCi, Baltimore, USA, October 5.

Dust properties in circumstellar environment, MPI, Heidelberg, Germany, October 20.

Observational techniques and Instrumentation (2 Lectures) IUCAA Introductory Workshop in Astronomy and Astrophysics, Panjab University, Chandigarh, November 19-23.

Dust models and interstellar extinction, AAO Special Colloquium at Anglo-Australian Observatory, Sydney, Australia, March 8.

Artificial neural networks : A robust classification tool for astronomy, Colloquium at PRL, Ahmedabad, March 17.

Ajit Kembhavi

Surveying the sky : A new paradigm for astronomy, IUCAA Resource Centre, University of Calcutta, Kolkata, April 21.

Large and extremely large telescope, 11th Indian Astronomy Olympiad 2009, Homi Bhabha Centre for Science Education, Mumbai, May 16.

Compact stellar object (2 lectures), VSP / VSRP / Refresher Course, IUCAA, Pune, May 18.

Morphological correlations and formation mechanisms for lenticular, European Southern Observatory, Garching, June 2.

Physics of warm absorbers in active galactic nuclei, Max-Planck-Institute fur Extraterrestrische Physik (MPE), Garching, June 3.

Galileo-astronomer and physicist, M. G. University, Kottayam, September 9.

Fundamental correlations in galaxies, University of Kentucky, USA, September 29.

Virtual observatories : Data visualisation, statistics and machine learning, University of Kentucky, USA, September 30.

Data visualisation, statistics & machine learning, ADASS 2009, Japan, October 7.

Virtual observatories, high performance computing in observational astronomy : Requirements and Challenges, IUCAA, Pune, October 12.

The end state of stars, IUCAA Introductory Workshop in Astronomy and Astrophysics, Panjab University, Chandigarh, November 19.

Modern astronomy - Big data, super computers and virtual observatories, International Year of Astronomy (IYA) : Perspective and Challenges, Asiatic Society, Kolkata, November 21.

From Galileo to Einstein-A Journey Over 400 Years, Astronomy in India-Seminar (IYA), NIO, Goa, December 12.

Telescope-From Galileo to the extremely large telescopes, State level camp for College Students, Pt. Ravishankar Shukla University, Raipur, January 11.

Large optical telescopes and virtual observatories, Workshop on Astrophysics and Cosmology, University of Calcutta, Kolkata, January 13.

Stars at the centre of the galaxy, Workshop on Astrophysics and Cosmology, University of Calcutta, Kolkata, January 14.

Modern telescopes, West Bengal State University Barasat, January 12.

Nuclear synthesis (2 lectures) at University of Calcutta for Presidency College Students as part of M. Sc. Special paper in Astronomy, January 13-14.
Convection (2 lectures) at University of Calcutta for Presidency College Students as part of M. Sc. Special paper in Astronomy, January 13-14.

Modern astronomy-Big data, supercomputers and virtual observatories, Interdisciplinary Seminar, New Frontiers in Science : Challenges and Opportunities, Jai Hind College, Mumbai, January 18.

One small library and data centre-From there to eternity, International Conference on Library Information Services in Astronomy (LISA VI) IUCAA, Pune, February 17.

Orbits of stars at the galactic centre, Training Programme on Modern Trends in Celestial Mechanics and Astronomy, Deshbandhu College, University of Delhi, March 17.

Collaborative Indian projects in physics and astronomy, The First Asia-Europe Physics Summit (ASEPS), Ibaraki, Japan, March 24.

Ranjeev Misra

IYA activities in India, Invited talk in the closing ceremony of the International Year of Astronomy, Padova, Italy, January 2010

Spectral and temporal properties of ultra-lLuminous x-ray sources, Seminar at INAF, Merate, Italy, January 12 2010.

Analytical estimate for errors on cross-correlation, phase and time-lags between two light curves, Probing Strong Gravity near Black Holes Conference, Prague, Czech Republic, February 18, 2010.

Vijay Mohan

Astronomical photometry (2 lectures), Refresher Course, held at IUCAA (May-June 2009).

Astronomical detectors and *Photometry* (2 lectures), IUCAA-MGU Workshop on Galaxy Astronomy, M. G. University, Kottayam, October 30 - November 5.

Celestial co-ordinates and *Telescopes and detectors* (2 lectures), IUCAA Introductory Workshop in Astronomy and Astrophysics, Department of Physics, Panjab University, Chandigarh, November 19- 23, 2009.

Astronomical telescopes, Y. C. Institute of Science, Satara, Decmber 4.

Jayant Narlikar

The amazing world of astronomy, Department of Physics, Indian Institute of Space Science and Technology, Thiruvananthapuram, April 1.
Newtonian cosmology (2 lectures) Vacation Students' Programme, IUCAA, Pune, May 19, 2009.

Cosmology and the origin of nuclei, 7th International Conference on Modern Problem of Nuclear Physics, Institute of Nuclear Physics, Uzbekistan Academy of Sciences, Tashkent, Uzbekistan, September 23.

Cosmology (2 lectures), Presidency College, Kolkata delivered at IUCAA, Pune, October 20 and October 21.

Ekeesavi sadi me vidyan aur usme Hindi ka yogdan, (Hindi's contribution to the science in the twentyfirst century) (in Hindi), Workshop at the Bhabha Atomic Research Centre, Mumbai, October 22.

The amazing world of astronomy, B. M. Birla Science Centre, Hyderabad, November 9.

Searches for micro-life in the Earth's atmosphere, Department of Physics, Saurashtra University, Rajkot, November 28.

Why study astronomy?, 1st TIFR Winter School in Astronomy and Astrophysics, Tata Institute of Fundamental Research, Mumbai, December 10.

Searches for micro-life in the Earth's atmosphere, 50th Annual Conference on Third Golden Era of Microbiology, Association of Microbiologists of India, National Chemical Laboratory, Pune, December 16.

Searches for micro-life in the Earth's atmosphere, Visvesvaraya National Institute of Technology, Nagpur, January 28.

Why study astronomy?, Physics Department, Rashtrasant Tukadoji Maharaj Nagpur University, Nagpur, January 29.

Searches for micro-life in the Earth's atmosphere, Institute of Mathematical Sciences, Chennai, February 10.

Keynote address, LISA VI Conference, IUCAA, February 15.

Search for life in the universe, a talk delivered during the Seminar on Modern Development in Astronomy, Mauritius, March 3.

Electromagnetism and gravitation : Comparison and contrast (2 lectures) Indian Institute of Science Education and Research, Pune, March 11 and 12, 2010.

The role of the gravitational constant in astronomy, Keynote address, Workshop-cum-Training Programme on Modern Trends in Celestial Mechanics and Astronomy, University of Delhi, Delhi, March 17.

The amazing world of astronomy, Jaypee Institute of Information Technology, Noida, March 18.

The expanding horizons of astro-biology, R. S. Pandey Distinguished Seminar, Department of Mechanical Engineering, Indian Institute of Technology, Kanpur, March 29.

The amazing world of astronomy, Indian Institute of Technology, Kanpur, March 30.

T. Padmanabhan

Gravity as emergent phenomenon, Invisible Universe International Conference, UNESCO Palace, Paris, June 29.

A thermodynamic perspective of gravity, Conference on Foundations of Space and Time, Cape Town, August 10.

A thermodynamic perspective of gravity, Colloquium at CERN, October 21.

Matters of gravity, Conference on Perspectives in Fundamental Research, TIFR, Mumbai, March 3/4.

A passion for the cosmos, Pisharoty Memorial Lecture, Kerala Science Congress, Peechi, Thruvananthapuram, January 29. (Award Lecture)

Gravity as Emergent Phenomena, University of Oxford, June 12.

Gravity as emergent phenomena, Cavendish Laboratory, Cambridge, July 14.

Maulik Parikh

Topological effects in classical and quantum gravity, Conference on New Horizons in Particle Cosmology, University of Pennsylvania, Philadelphia, USA, December 2009.

Topological effects in classical and quantum gravity, University of Maryland, College Park, Maryland, USA, October 2009.

Black holes and the structure of spacetime, University of Chicago, Chicago, USA, October 2009.

Topological effects in classical and quantum gravity, Yale University, New Haven, Connecticut, USA, October 2009.

Topology and relativity, University of Oxford, Oxford, UK, October 2009.

Black holes and the structure of spacetime, DAMTP, University of Cambridge, UK, October 2009.

Topological effects in classical and quantum gravity, Queen Mary, University of London, UK, October 2009.

Fun with topology and relativity, IUCAA, Pune, October 2009.

Spacetime holography, Ecole Normale Superieure, Paris, France, July 2009.

Spacetime holography, FQXi 2nd International Conference on Foundation Questions in Physics and Cosmology, Azores, Portugal, July 2009.

Black holes and the structure of spacetime, Paris Observatory, Meudon, France, June 2009.

Black holes and the structure of spacetime, University of Orsay, Orsay, France, June 2009.

Black holes and the structure of spacetime, Institute of Astrophysics, Paris, France, June 2009.

Black holes and the structure of spacetime, University of Tours, Tours, France, June 2009.

Black holes and the structure of spacetime, VUB-ULB-Solvay Institute, Brussels, Belgium, June 2009.

Black holes and the structure of spacetime, Columbia University, New York, USA, May 2009.

Black holes and the structure of spacetime, Dutch Joint Theoretical Cosmology Meeting, University of Amsterdam, the Netherlands, May 2009.

Black holes and the structure of spacetime, Astroparticles and Cosmology (APC) Laboratory, Paris, France, April 2009.

Surajit Paul

Simulations of shock evolution in major cluster mergers using super and high performance computing facility (Presented with Joydeep Bagchi), Poster presentation at the conference High Performance Computing in Observational Astronomy : Requirements and Challenges, October 12 - 16.

Evolution of shocks and turbulence in structure/cluster formation, Mini-workshop on CMB Related Research, December 10.

Injection of turbulence by evolving shocks in major merging clusters, RRI, Bangalore, February 16, 2010

Evolution of shocks and turbulence in major galaxy-cluster merging events, Argelander-Institut für Astronomie, University of Bonn, Germany, March 23, 2010

Evolution of shocks and turbulence in major merging clusters, Institute of Astrophysics (IAP), Potsdam University, Germany, March 24, 2010.

Evolution of structure formation shocks and turbulence in web-like filamentary universe, ITA, Heidelberg University, March 31, 2010

A. N. Ramaprakash

Future large telescopes, VSP Special Lecture, IUCAA, May 26, 2009.

IUCAA facilities, IUCAA Reunion Meeting, IUCAA, August 10, 2009

Polarimeter, telescope and relatives, IUCAA Reunion Meeting, IUCAA, August 13, 2009

An overview of the thirty metre telescope, National Meeting, IIA, Bengaluru, October 10, 2009

An overview of the thirty metre telescope, PRL, Ahmedabad, November 30, 2009.

An astronomical future for astronomy, TIFR Winter School, December 09, 2009

Swara Ravindranath

Galaxy morphology at high redshifts with WFC3, 215th Meeting of the American Astronomical Society : special session on Morphology at High-z; Washington DC, USA, January 7, 2010.

Observing the growth of galaxies at early cosmic epochs, Frontiers in Physics - II at Ferguson College, Pune, February 19, 2010.

Varun Sahni

The enigma of dark matter and dark energy, Milestones in Astronomy, Nehru Planetarium, Mumai, October 28, 2009.

Dark Energy, Indian Institute of Astrophysics, Bangalore, October 13, 2009.

Tarun Souradeep

Peering beyond `standard' cosmology, Plenary talk at Science Without Boundaries, ICTS Inaugural meeting, Bangalore, December 27-30, 2009.

Beyond 'standard' cosmology with the cosmic microwave background, NISER, Bhubaneshwar, December 4, 2009.

Mapping the stochastic gravitational wave background, First Galileo-Xu Guanqui Meeting, Shanghai, China, October 25-30, 2009.

Hunt for signatures beyond the 'standard' cosmological model, BIPAC, Oxford, June 23, 2009.

Searching beyond 'standard' cosmology in the CMB, IoA, Cambridge, July 1, 2009.

Searching beyond 'standard' Cosmology in the CMB, Imperial College, London, July 3, 2009.

Searching beyond 'standard' Cosmology in the CMB, APC, Paris, October 8, 2009.

CMB power spectra sans for ground modeling, India-South Africa Workshop, IUCAA, December 9, 2009.

Case for IndIGO satellite meeting on GW, IUCAA Reunion meeting, IUCAA, August 10, 2009.

Searching for subtle deviations from 'standard' cosmology, Raman Research Institute, Bangalore. July 13, 2009.

Beyond the CMB power spectrum, Interntional Workshop on HPC in Astronomy and Astrophysics, IUCAA, October 14, 2009.

Cosmology : Large scale structure and cosmic microwave background, IUCAA-NCRA Radio-Astronomy School, IUCAA, December 23, 2009.

Mathematical challenges in cosmic microwave background research Workshop on Astrophysics and Cosmology, Department of Applied Mathemtics, Kolkata University, January 14, 2010.

Cosmology : Large scale structure and cosmic microwave background, *Workshop on* Astrophysics and Cosmology, Department of Applied Mathematics, Kolkata Universit, January 13, 2 010.

Perturbed universe with the cosmic microwave background, National Workshop on Astronomy, University of Kashmir, November 3, 2009.

Emerging frontiers in cosmic microwave background research, National Workshop on Astronomy, University of Kashmir, November 4, 2009.

R. Srianand

QSO absorption lines and fundamental constants (2 talks) in Leiden, The Netherlands, May 2009.

Probing the universe and fundamental physics using QSO absorption lines, IAU General Assembly, Brazil, August 2009.

Probing the universe with QSO absorption lines, TIFR, Mumbai, December 2009.

QSO-galaxy connection using 21-cm absorption lines, SALT-MeerKAT workshop, Capetown, South Africa, November 2009.

Cold gas as high redshifts, Indian Academy of Sciences, mid-year meeting, Bangalore, November 2009.

Mudit Srivastava

Design and development of an optical fibre based Integral Field Unit (IFU) on IUCAA 2 m Telescope, Leiden Observatory, Leiden, The Netherlands, December 17, 2009.

Imaging characteristics of Ultra-Violet Imaging Telescope (UVIT) through numerical simulations, Institute for Astronomy and Astrophysics (IAAT), University of Tuebingen, Germany, December 11, 2009.

K. Subramanian

Magnetic field generation in the early universe, Meeting on Astrophysical Magnetohydrodynamics, Hesinkin, Finland, April 2009.

Magnetic field generation in the early universe, Meeting on Cosmic Magnetic fields, Ascona, Switzerland, June 2009.

Magnetic fields - from the early to the contemporary universe, Raman Research Institute, Bangalore, November 2009.

Magnetizing the universe, Centre for Basic Sciences Mumbai, November 2009.

Magnetic fields in the early universe, Heidelberg Joint Astronomical Colloquium, Heidelberg, Germany, December 2009.

Galactic outflows and the IGM, Harish Chandra meeing on Cosmic Reionization, Allahabad, February 2010.

Magnetic fields in the early universe, International Space Science Institute Workshop, Bern, Switzerland, March 2010.

(b) Lecture Courses [3 or more talks on one theme]

Dipankar Bhattacharya

IDC201 : Astronomy and astrophysics (Part I- 10 Lectures), IISER Mohali, Chandigarh, August 19 - 29, 2009.

Fluids in astrophysics (3 Lectures) IUCAA Vacation Students' Programme, May 13 - 15.

PHY352 : Fluid mechanics (Part II - 9 lectures), IISER Pune, September-October 2009.

Stellar structure and evolution (4 Lectures) at DAA Winter School on Astronomy and Astrophysics, TIFR, Mumbai, December 6 -10, 2009.

Gulab Chand Dewangan

`X-ray emission from active galactic nuclei, 3 lectures at Tezpur University, Tezpur (Assam) October 21- 23, 2009.

X-ray astronomy and active galactic nuclei, 3 lectures at the Kashmir University, Srinagar November 3-5, 2009.

Sanjeev Dhurandhar

Black holes and gravitational waves, (4 lectures) Introductory Summer School on Astronomy and Astrophysics, and Vacation Students' Programme, IUCAA, May - June 2009.

General r elativity and gravitational waves (2 lectures) IUCAA Workshop on Astrophysics and Cosmology, Kolkata, January 13 – 14, 2010.

Ranjan Gupta

Stellar Spectroscopy, (3 Lectures), VSP/VRSP/Refresher course, IUCAA, June 1- 3, 2009.

Observational Astronomy, (5 Lectures), Advance Meteorology Training Batch 2009 - 2010, Central Training Institute, IMD, Pune, January 22 - 29, 2010.

Telescopes in this millennium; Astronomical instrumentation; and Career opportunities for students in the field of Astronomy, (3 Lectures), National Workshop on Observational Astronomy, Kalpana Chawla Centre for Space and Nano Sciences, Kolkata, August 21, 2009.

Ajit Kembhavi

Stellar structure and evolution (5 lectures), VSP / VSRP / Refresher Course, IUCAA, Pune, May-June 2009.

Stellar structure (8 lectures), Presidency College Students, Part of M. Sc. Special Paper in Astronomy, IUCAA, Pune, October 19 - 29, 2009.

Ranjeev Misra

Radiative and accretion processes in astrophysics (4 lectures), IUCAA Workshop in Astronomy and Astrophysics, North Bengal University, Silguri, March 2010.

Radiative and accretion processes in astrophysics (4 lectures), IUCAA Workshop in Recent Trends in Astronomy, Tezpur University, October 2009.

Radiative and accretion processes in astrophysics (4 lectures) IUCAA Workshop in Advances in Astronomy, Kashmir University, Srinagar, November 2009.

Radiative and accretion processes in astrophysics (6 lectures), VSP/Refresher Course, IUCAA, May 2009.

Vijay Mohan

Observational astronomy (M. Sc. students) (3 lectures) Gauhati University, Guwahati, May 5-11, 2009.

J. V. Narlikar

Ordinary differential equations (5 lectures), Motivational Bridge Course, organized by the Indian Academy of Sciences, Gogate Jogalekar College, Ratnagiri, April 6 - 10, 2009.

Is modern cosmology a scientific theory? (3 lectures), Indian Institute of Advanced Study, Shimla, May 25 -29, 2009.

Interaction between astronomy, physics and mathematics, (4 lectures), Chennai Mathematical Institute, Chennai, February 8 - 11, 2010.

Cosmology from the sidelines, (3 lectures), DST Centre for Interdisciplinary Mathematical Sciences, Banaras Hindu University, Varanasi, February 22 - 24, 2010.

Cosmology (3 lectures), Centre for Theoretical Physics, Jamia Millia Islamia, New Delhi, March 15 - 18, 2010.

T. Padmanabhan

Special general relativity (3 lectures), VSP, Refresher Course in Astronomy and Astrophysics, IUCAA, Pune, May 11- 13, 2009.
Advance topics in general relativity (15 lectures), University of Geneva, October 7 -30, 2009.

Swara Ravindranath

Galaxies (3 lectures), VSP/VSRP/Refresher Course, 1 session on SExtractor, IUCAA, May - June 2009.

Galaxies (3 lectures), Workshop on Recent Trends in Astronomy, Tezpur University, Assam, October 2009.

Galaxies (3 lectures), Workshop on Advances in Astronomy, Kashmir University, Srinagar, November 2009.

A. N. Ramaprakash

Instrumentation and detectors for astronomy (4 lectures), VSP and Refresher Course, May 21-25, 2009.

Astronomical techniques (6 lectures), TIFR Winter School, TIFR, Mumbai, December 9 - 12, 2009.

Tarun Souradeep

Cosmology with CMB and LSS (4 lectures), Vacation Students' Programme, Refresher Course, IUCAA, May - June 2009.

R. Srianand

ISM and IGM, (5 lectures), Vacation Students' Programme, Refresher Course, IUCAA, May-June 2009.

K. Subramanian

Magnetohydrodynamics, (3 lectures), Vacation Students' Programme, Refresher Course, IUCAA, June 2009.

Mean field dynamos and magnetic helicity (4 lectures), Nordita Workshop on Dynamos, Nordita, Stockholm, Sweden, January 2010.

Cosmology (45 hr course), African Institute of Science and Technology, Abuja, Nigeria, March 2010.

(VIII) SCIENTIFIC MEETINGS AND OTHER EVENTS

Refresher Course in Astronomy and Astrophysics for College / University Teachers

Participants and Lecturers of the Refresher Course in Astronomy and Astrophysics

The Refresher Course in Astronomy and Astrophysics for college and university teachers was held during May 11 - June 12, 2009 at IUCAA. Participants were selected from all over India and twelve highly interested participants attended the course. The course introduced Astronomy and Astrophysics in the first week, and covered more advanced topics in the following weeks. An important aspect of the programme was the data analysis sessions, where the participants were given hands-on experience on the use of computers, astronomical data archives and virtual libraries. They also analysed photometric and spectroscopic data obtained with 2 m optical telescope at IUCAA Girawali Observatory (IGO). The faculty members, post-doctoral fellows, and research scholars of IUCAA delivered the lectures and conducted lab sessions with great enthusiasm. A few faculty members and visitors from outside IUCAA have also delivered lectures. The scientific and the administrative staff were of vital help in ensuring that the course ran smoothly. Gulab Dewangan was the faculty coordinator of the Refresher Course, and A. N. Ramaprakash assisted in the coordination. The participants also visited the IGO and the Giant Metrewave Radio Telescope (GMRT). At the end of the course, it was clear that the participants benefited substantially and were inspired to take up research and teaching in astronomy and astrophysics at their home institutions.

Vacation Students' Programme

Participants and Lecturers of the Vacation Students' Programme

The Vacation Students' Programme (VSP), for students in their penultimate year of M. Sc. (Physics) or Engineering degree course was held during May 11 - June 26, 2009. Exceptionally motivated final year B. Sc Students were also invited. This year, four students (two of whom were B. Sc.) participated in this programme. The participants attended about 50 lectures, dealing with a wide variety of topics in Astronomy and Astrophysics, given mostly by the members of IUCAA. They also did a project with one of the faculty members of IUCAA during this period. K. Subramanian was the faculty coordinator of this programme.

First IUCAA Reunion Meeting

IUCAA has recently completed twenty glorious years and to celebrate this occasion, the First IUCAA Reunion Meeting was arranged during August 11-14, 2009. The former Faculty Members, Post-doctoral Fellows, Research Scholars, Senior Visiting Associates, Governing Board and Council members, and distinguished members of international community, who have been on the Scientific Advisory Committee, were invited to attend this meeting. There were 150 participants attending the lively academic, cultural, and social programmes. This meeting was envisaged as a get together of all former IUCAAites, who are spread around the globe at highly acclaimed academic environment, to contribute their expert opinion on the future scientific direction for IUCAA, and seek ways in which they could remain engaged in the growth and expansion plans of the institute. This also gave the alumni an occasion to recall the fond memories of their stay at IUCAA and proved to be emotionally enriching for many of them.

Glimpses of the First IUCAA Reunion Meeting

The scientific theme of this meeting was Gravitation and Astronomy : Frontiers in Theory and Observation. Following were the major topics on which lectures were conducted : Gravitational Waves, Cosmology, Observational Astronomy and Data Analysis Techniques, Classical Gravity, Instrumentation, Theoretical Astrophysics, and Quantum Aspects of Gravity and Early Universe. There were three panel discussions covering different aspects on (1) IUCAA Gravitational Wave Research Legacy, (2) IUCAA Scientific Programmes : Present and Future, and (3) IUCAA and the World. On August 10, 2009, there were two parallel satellite meetings on Indian Gravitational Waves Experimental Effort-Scope and Feasibility, and Large Data Sets and Follow up Observations. These focused meetings helped to shape the discussions during the meeting.

The Director, Naresh Dadhich, and the senior Faculty Member and Distinguished Professor, Shyam Tandon, would be retiring, and there was a special function to felicitate them. It was a very touching moment for everyone, because of their long association and valuable contribution to IUCAA. A performance of the famous cartoonist, R. K. Laxman's, `Common Man', by Ajit Kelkar was also arranged on one of the evenings. Overall, it was a home coming feeling for everyone. Tarun Souradeep coordinated the scientific programmes, and V. Chellathurai took care of the local arrangements with the help of many others.

Introductory Workshop for ASTROSAT Data Products Software Team

Participants of the Introductory workshop for ASTROSAT Data Products Software Team

With ASTROSAT, the Indian Multiwavelength Astronomy Satellite, due for launch next year, software teams in ISRO have recently been entrusted with the responsibility of the development of software for the data pipeline for its various instruments. A team in Space Application Centre (SAC), Ahmedabad has been given the responsibility of developing the pipeline to produce final processed science data products for release.

In order to acquaint this team with the astronomical context involved, and the various necessary steps in the data processing, a 5-day workshop was organised in IUCAA during June 29 to July 3, 2009. Eight members of the software team from SAC participated. Over 14 hours of lectures were delivered by about a dozen lecturers from IUCAA; TIFR, Mumbai; and RRI, Bangalore. All five payloads - the Large Area X-ray Proportional Counter (LAXPC), the Ultraviolet Imaging Telescope (UVIT), the Soft X-ray Telescope (SXT), the Cadmium Zinc Telluride Imager (CZTI), and the Scanning Sky Monitor (SSM) were discussed in detail by members of the respective instrument teams. In addition, more than 15 hours of demonstration and hands-on data analysis sessions were organised.

The topics covered included introduction to basic astronomy and astrophysics, the special niche areas of ASTROSAT, such as, multi-wavelength timing, broadband spectroscopy and ultraviolet imaging, as well as technical details of the five science payloads and the steps needed to convert the data recorded by them to the expected release level data products. The hands-on sessions demonstrated examples of such data products, and how an astronomer would use them to derive final scientific conclusions.

Following this workshop, the Data Products team has started work on the required software development in earnest. This activity is now continuing.

Workshop on Recent trends in Astronomy and Astrophysics at the Department of Physics, Tezpur University

Participants and Lecturers of the workshop

Department of Physics, Tezpur University has organized a Workshop on Recent trends in Astronomy and Astrophysics, during October 21-23, 2009 to mark the International Year of Astronomy. The workshop was sponsored by IUCAA. The idea behind arranging the workshop was to motivate young students and faculty members of the North-East region to pursue higher studies in the field of Astronomy and Astrophysics, and give them exposure to the latest developments in this field. The workshop was inaugurated by H. Duorah, former Vice Chancellor, Gauhati University. M. K. Choudhury, Vice Chancellor of Tezpur University assured of extending all kinds of support in starting Astrophysics specialization in M. Sc. programme in the Department of Physics, Tezpur University, during the inaugural session of the workshop. Noted astrophysicists Ranjeev Misra, Swara Ravindranath, and Gulab Dewangan from IUCAA, and M. P. Bora, and Archana Bora from Gauhati University, delivered inspiring talks at the workshop. Some of the topics of discussion were radioactive processes and accretion disks, galaxies, structure and evolution, X-ray astronomy, active galactic nuclei, and plasma processes in astrophysical environments. Ranjeev Misra delivered a public talk on "*Observational evidence for black holes*". Participants from various universities and colleges of North-Eastern states attended the workshop. The workshop was coordinated by Ranjeev Misra and Neelakshi Das.

Workshop on Galaxy Photometry

Participants of the Workshop on Galaxy Photometry

A Workshop on Galaxy Photometry was held during October 30 to November 5, 2009 at the School of Pure and Applied Physics, Mahatma Gandhi University, Kottayam, Kerala. It was inaugurated by the Vice Chancellor, Rajan Gurukkal, in the presence of V. C. Kuriakose from the IUCAA Resource Center at the Cochin University of Science and Technology, Kochi.

There were twenty-seven registered participants, who were students from various science and engineering colleges and teachers from colleges and higher secondary school. The workshop concentrated on various projects.

There were five resource persons from the region, mentoring the projects. In addition to the project lectures, there were several invited lectures by resource persons from various institutions (IUCAA, NCRA, RRI, ISRO, CUSAT, and St. Joseph's College, Bengaluru). Rajaram Nityananda (Director, NCRA) delivered the third lecture of the Frontier Lecture Series dedicated to the memory of G. V. Vijayagovindan, titled Galaxies : Today, Yesterday and the Day Before.

In addition to the workshop lectures, there were two parallel sessions : (i) Payload Engineering from Aryabhatta to the Chandrayan by Ramakrishna Sharma from ISAC, Bengaluru, for 30 students from the Rajiv Gandhi Institute of Technology, Pampadi, and from the University Centre for Intellectual Property Rights.

(ii) Astroinformatics by Ninan Sajeeth Philip (IUCAA Associate from St. Thomas College, Kozhencheri) for 50 students from the Computer Science and Bioscience departments of MGU. A special lecture on the Origin of Life, and also a Sky Watch programme was conducted by Arvind Paranjpye from IUCAA. It was very enthusiastically received by the participants and the university community. There was also an evening cultural program on the penultimate day of the workshop.

The various project groups are in touch with their mentors, and the work that started at the workshop will be completed during the extended sequel that will run up to three months. The coordinators of this workshop were K. Indulekha from MGU and Ninan Sajeeth Philip from IUCAA side.

Introductory Workshop on Astronomy and Astrophysics

Participants of the Introductory Workshop on Astronomy and Astrophysics

An Introductory Workshop on Astronomy and Astrophysics was held at the Department of Physics, Panjab University, Chandigarh, during November 19 - 23, 2009. The workshop was organized as a part of the celebrations of the International Year of Astronomy (IYA- 2009). Besides, the workshop was also conducted as a part of IUCAA's sustained support for the growth of Astronomy and Astrophysics in the country. The workshop was primarily sponsored by IUCAA, with a partial support from the Indian Space Research Organization (ISRO), Bengaluru. The main objective of the workshop was to introduce the field of Astronomy and Astrophysics to B. Sc. and M. Sc. students from various institutes, colleges, and universities of north India. There were 35 students, selected from a total of 120 applicants.

The workshop was inaugurated by R. C. Sobti, Vice Chancellor, Panjab University, M. Gupta, Chairman, Department of Physics, gave introductory remarks on the workshop. He presented a brief over-view of the departments' academic activities. The inaugural talk on *The end state of the stars* was delivered by Ajit Kembhavi, the Director, IUCAA, Pune. He also gave a popular evening lecture on *From Galileo to Einstein - A journey over 400 Years*. The popular lectures were attended by a wide audience, comprising of the workshop participants, students and faculty members from various departments of the university.

During the course of five days, eleven eminent researchers from various institutes and universities delivered lectures on a wide-range of topics in the field of Astronomy and Astrophysics. H. P. Singh, University of Delhi, familiarized the students with the basic stellar properties. Ranjan Gupta, IUCAA, Pune, gave lectures on the observaional techniques and instruments. He also delivered an evening popular lecture on modern telescopes. The concepts of coordinate system and telescope basics were taught by Vijay Mohan, IUCAA, Pune. P. S. Goraya, Punjabi University, Patiala, discussed the properties and the nature of the interstellar medium. The physics of the stellar structure and evolution was presented by S. Sahijpal, Panjab University. N. Iqbal, Kashmir University, gave lectures on the galaxies. A. Rawat also delivered a lecture on the nature and morphology of galaxies. The lectures on cosmology were delivered by T. R. Seshadri, University of Delhi. A. Ranade, Vigyan Prasar, and S. Deb, University of Delhi, gave lectures on Practical Astronomy, Solar eclipse, and Astronomy with small telescopes. They also conducted laboratory sessions on data analysis and assignments. The night sky watching activities with a 11" telescope were carried out by S. Sahijpal and his students.

The workshop concluded with a general discussion among the resource persons and the participants on the career opportunities and the scope of research in the field of Astronomy and Astrophysics. The students gave their feedback regarding the academic and organizational aspects of the workshop. The coordinators of this workshop were S. Sahijpal from Panjab University and Ranjan Gupta from IUCAA.

National Workshop on Advances in Astronomy and Astrophysics

Participants of the National Workshop on Advances in Astronomy and Astrophysics

Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune, in collaboration with the Department of Physics, University of Kashmir, Srinagar, organized a 4-day *National Workshop on Advances in Astronomy and Astrophysics*, at University of Kashmir, Srinagar, during November 3 - 6, 2009. Among the more than one hundred registered participants of the workshop were college and university teachers; scientists from BARC (NPL), Zakura; faculty and researchers from NIT, Hazratbal; research scholars and M. Sc. students from the host department.

With the underlying aim to expose the participants to the frontline areas of research in Astronomy and Astrophysics, a number of frontline topics, like Galaxy Formation (Swara Ravindranath, IUCAA), Physics of Black Holes (Ranjeev Misra, IUCAA), CMB (Tarun Souradeep, IUCAA), X-ray Astronomy (Gulab Dewangan, IUCAA), Cosmological N-body Simulations (Jasjeet S. Bagla, HRI, Allahabad), Cosmological Many-body Problem (Farooq Ahmad, University of Kashmir), etc., were covered. During the workshop, it was made amply clear that this was indeed the most exciting time for research in Astronomy and Astrophysics and, while many of the other fields were saturating, it was time to explore the prospect of pursuing an exciting career in Astronomy and Astrophysics.

The workshop was taken very seriously by the University of Kashmir. This was reflected by the fact that the Minister for Science and Technology from the Government of Jammu and Kashmir, Aga Ruhullah and Principal Secretary to the Chief Minister, Khursheed A. Ganai, were respectively, the Chief Guest and the Guest of Honour on the inaugural function of the workshop. Their invitation was motivated by the fact that there was too little of investment in science in the region. This had an immediate positive effect. The Minister announced raising the financial support for organizing national workshops from a paltry Rs. 20, 000 to Rs. one lakh, and for organizing an International Workshop/ Conference to Rs. 2 lakhs. He also announced a generous financial support for the Optical Observational Facility being developed at Gulmarg by Farooq Ahmad. The Principal Secretary to the Chief Minister promised to use his good offices to do whatever he can for scientific advancement in the region. The plight of the research students, being paid too little fellowship, was addressed by Ranjeev Misra (Coordinator of the workshop) and the Vice-Chancellor of University of Kashmir, has already initiated steps to improve the situation.

Thus, while the workshop successfully fulfilled its primary objective of inspiring and updating the participants about the current research in Astronomy and Astrophysics, it triggered many more positive initiatives. The coordinators of this workshop were Manzoor A. Malick from University of Kashmir, and Ranjeev Misra from IUCAA.

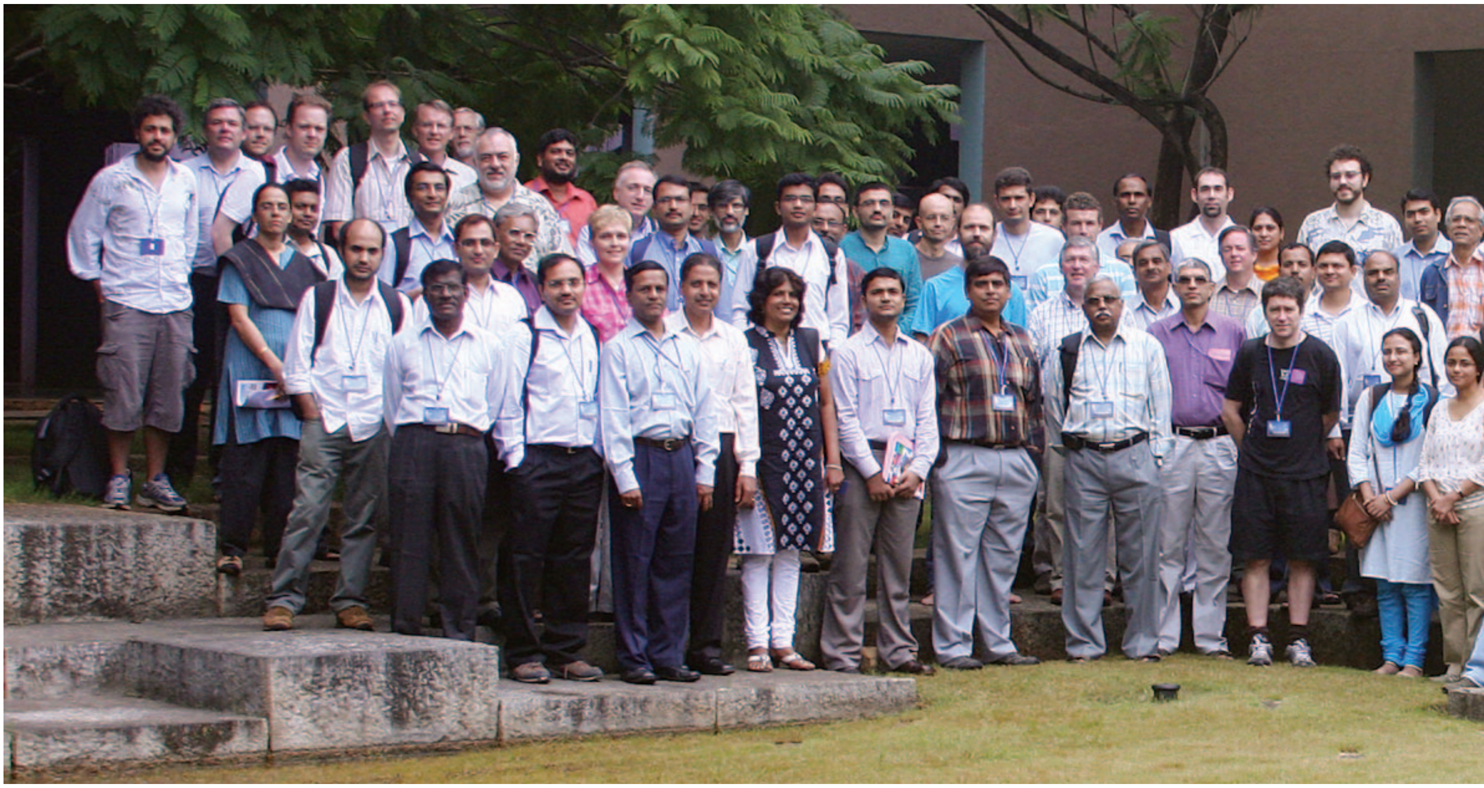
Mini-workshop on European and Indian Approaches to Calculus

IUCAA conducted a Mini-workshop on European and Indian Approaches to Calculus, during November 17 - 18, 2009. The immediate impetus for the meeting was the visit of Alex Craik (University of St. Andrews), who has a strong interest in the history of the ideas and techniques running through the development of calculus in Europe, and the main aim was to explore its parallels with the earlier work on the calculus of trigonometric functions by the so-called Kerala school. Five scholars from outside IUCAA were invited to give lectures. The speakers included :

(i) Alex Craik (University of St. Andrews), (ii) Madhukar Mallayya (Mar Ivanios College, Thiruvananthapuram), (iii) Roddam Narasimha (Jawaharlal Nehru Centre, Bengaluru), (iv) S. G. Dani (TIFR, Mumbai), (v) Bhagyashree Bavare (Mumbai University), and (vi) P. P. Divakaran (IUCAA).

There were times for much animated discussions inside and outside the lecture hall, with good participation from faculty and students of IUCAA, as well as several other interested people from Pune. On the whole, the workshop can be said to have given most participants a clearer idea of the originality of the Indian side of the story of calculus, the European side of it being much better known to most of us.

International workshop on High Performance Computing



Participants of the International Workshop on High Performance

An International Workshop on High Performance Computing in Observational Astronomy : Requirements and Challenges was held at IUCAA during October 12 - 16, 2009. The workshop was organized jointly by C-DAC, IUCAA and NCRA. The aim of the workhsop was to discuss computationally intensive techniques and new software approaches that were important for different branches of observational astronomy. Requirements for future large instruments, including the Square Kilometre Array Radio Telescope, Giant Segmented Mirror Optical Telescopes, the Large Synoptic Survey Telescope, the ASTROSAT mission, the upgraded Giant Metrewave Radio Telescope and several others were addressed. There was enthusiastic participation from both academic institutions and the IT industry. The number of participants was about 150, including 45 from overseas.

The workshop had keynote lectures in the morning, reviewing the emerging computing requirements in various branches of astronomy and also the emerging technologies for high performance computing solutions. During the rest of the day, in-depth discussions were conducted on specific areas, such as radio interferometry, transient analysis, pulsar astronomy, coded mask imaging, data analysis for gravitational waves and cosmic microwave background, pipelines for large optical imaging and spectroscopic surveys, data streaming, storage and dissemination techniques, as well as future computing, storage and network technologies.

It was clear from the presentations that observational astronomy was poised to become a major area of HPC applications. For example, the planned Square Kilometre Array Radio Telescope will require 100 petaflops of dedicated computing and several Exabytes of data storage to meet its regular operational requirements. Ideas of computing solutions appropriate for various applications were presented and debated upon. To keep the capital and operational costs in check, hybrid designs consisting of a mixture of FPGAs, GPUs and regular processors

Computing in Observational Astronomy : Requirements and Challenges.

were widely preferred.

One of the most important outcomes of this workshop was the coming together of similar interest groups from different academic institutions as well as the industry. Ideas of many collaborations emerged, several of which are now being actively pursued. The workshop provided a platform to showcase the work going on in Indian academic institutions and IT industry to tackle some of the relevant computing challenges, which evoked wide interest among the large, upcoming international astronomy projects to enter into technical collaboration with India.

International workshop on Library &

Participants of the

The 6th Library and Information Services in Astronomy (LISA VI) conference (http : //libibm. iucaa.ernet.in/ conf/index. html) was held during February 14-17, 2010 at IUCAA, Pune. LISA VI was organized jointly by the members of the Forum for Resource Sharing in Astronomy (FORSA) libraries, listed below, and hosted by IUCAA and NCRA, Pune.

* Aryabhatta Research Institute of Observational Sciences (ARIES), Nainital.
* Bose Institute, Kolkata.
* Harish-Chandra Research Institute (HRI), Allahabad.
* Indian Institute of Astrophysics (IIA), Bangalore.
* Inter-University Centre for Astronomy and Astrophysics (IUCAA), Pune.
* National Centre for Radio Astrophysics (NCRA), Pune.
* Osmania University – Centre for Advanced Sudies in Astronomy (CASA), Hyderabad.
* Physical Research Laboratory (PRL), Ahmedabad.
* Raman Research Institute (RRI), Bangalore.
* Saha Institute of Nuclear Physics (SINP), Kolkata.
* S. N. Bose National Centre for Basic Sciences (SNBNCBS), Kolkata.

Information Services in Astronomy

LISA Conference

* Tata Institute of Fundamental Research (TIFR), Mumbai.

Critical financial support was received from Astronomical Society of India (ASI), some FORSA member institutes, in addition to the funds received from LISA V organizers.

The theme of the conference was "21st Century Astronomy Librarianship : From New Ideas to Action" and the conference discussed issues concerning the future of librarianship, Web 2. 0/3. 0, use, access and metrics, resource management and intellectual property, preservation and archiving, and the virtual observatory.

The keynote address was delivered by Jayant V. Narlikar, Emeritus Professor and Founder-Director, IUCAA on the topic "Role of a Virtual Library in the Coming Decades. " This was followed by a unique programme "Honouring our Mentors" to felicitate 17 retired astronomy library professionals from India and abroad in recognition of their contribution to the profession, at the hands of Rajaram Nityananda, Centre-Director, NCRA.

The scientific sessions scheduled on Tuesday, February 16, 2010 was held at GMRT-TIFR, Narayangaon. The participants were given a tour of the radio telescope after the scientific session, which was highly appreciated.

The invited talks were delivered by A. R. D. Prasad (D. R. T. C., Bangalore) in the session on 'Future of Libraries", Subbiah Arunachalam, (Information Consultant, Chennai) and Salvatore Mele (SCOAP, CERN, Switzerland) in the session on Open Access, and Ajit K.

Kembhavi (Director, IUCAA) in the session on Virtual Communities.

A publisher round table session was organized on the concluding day of the conference with a participation of four publishers, viz. Astronomical Society of the Pacific (ASP), EDP Sciences, Institute of Physics (IOP), and John Wiley & Sons.

All the scientific sessions were video recorded using EyA (Enhance your Audience), which is an innovative automated audio/video/slide recording system, developed by Science Dissemination Unit (SDU), ICTP, Italy, to archive and share scientific lectures and talks carried out using digital presentations (PPT, PDF, animations, etc.) and specially traditional chalk boards found in classrooms. The talks will be available at the conference website (http : //libibm. iucaa.ernet.in/conf/index.php/LISA/conf) shortly.

The efforts taken by the Friends of LISA (FOL) Committee, which has been set up to assist librarians from developing countries to attend LISA conferences, ensured over 100 participants, with more than 50 participants coming from abroad representing 18 countries.

The proceedings of LISA VI have been sponsored by the Astronomical Society of the Pacific (ASP), who will publish it as an ASP Conference Proceeding.

Global Stone Sculpture Workshop

A Global Stone Sculpture Workshop was organised at IUCAA for two weeks during November 23 - December 5, 2009, in which 9 European sculptors participated and carved on marble stone. They carved on the general theme of Galileo and Astronomy, in resonance with the International Year of Astronomy and have left behind 9 wonderful pieces of art that IUCAA can be proud of. On two afternoons, the sculptors also gave presentations on their overall work to a general audience.

Participants of the Global Stone Sculpture Workshop

The sculptors included Michael Dan Archer (UK), Moises Preto Paulo (Portugal), Suzel Galia (France), Louise Plant (England), Vincent Williams, Lena Kristrom, Yvonne Nimar, Stefano Beccari (all from Sweden), and Caroline Ruizeveld (The Netherlands). They participated under the informal banner of Global Stone Workshop, which was organised by Stefano Beccari. It all came about with the efforts of our sculptor friend, Sharad Kapuskar, who was a regular participant of such workshops. IUCAA would like to warmly thank all the sculptors for their wonderful sculptures, and Stefano, Sharad and IUCAA staff for all their organisational and logistics effort.

Mini-workshop on CMB Related Research

Participants of the Mini-workshop on CMB Related Research

A Mini-workshop on CMB Related Research was organized at IUCAA during the period December 8 - 10, 2009. The informally structured meeting brought together a group of cosmology researchers from UKZN, Durban, South-Africa, and interested researchers in India to explore and initiate research collaborations. The topics covered were CMB anisotropy, Galactic foreground, Sunyaev-Zeldovich effect and cluster physics and SZ clusters surveys (in conjunction with x-ray, optical, IR cluster surveys). The participants included, the group from Durban led by Kavilan Moodley; Subhabrata Majumdar's group from TIFR, Mumbai; L. Sriramkumar at HRI, Allahabad, and members of IUCAA interested in CMB research. The meeting turned out to have the appropriate format and size that enabled close interactions in the focus area of research. This meeting was coordinated by Subharthi Ray from Durban and Tarun Souradeep from IUCAA. There are plans to hold similar meetings in the future in other areas of Astronomy and Astrophysics research to bring the researchers of India and South Africa closer through the ongoing exchange programme.

IUCAA-NCRA Radio Astronomy Winter School for College and University Students

Participants and Lecturers of the IUCAA-NCRA Radio Astronomy Winter School

The second Radio Astronomy Winter School for College and University Students was conducted by the IUCAA-NCRA Radio Physics Laboratory (RPL), a joint facility of IUCAA and the National Centre for Radio Astrophysics (NCRA), during December 21 - 29, 2009, at IUCAA and NCRA/TIFR Pune campuses. The winter school was attended by about 30 graduate and undergraduate students of Science and Engineering.

Following the goals envisaged for the Radio Physics Laboratory, a major emphasis was on a practical 'hands-on' approach for teaching radio astronomy. For understanding the practical/instrumental aspects of radio astronomy, the students conducted real-time astronomical observations of Sun and 21 cm spectral line from neutral Hydrogen gas of our Milky-Way using radio telescopes of 3 m and 4 m diameter, located at the NCRA east campus. They also performed Optical Faraday Rotation, Antenna and Wave Propagation experiments in the IUCAA's Radio Physics Laboratory, studying the interaction of polarized light with magnetized matter and understanding its application in Radio Astronomy. The antenna experiment allowed students to understand the characteristics of various types of antennae used in radio astronomy. In parallel, with these experiments, the students were also introduced to various important branches of Astronomy and Astrophysics, through a series of lectures delivered by faculty members from IUCAA, and NCRA/TIFR. The subject matter ranged from Radio Telescopes, Astronomical Coordinate Systems, Early Radio Astronomy, the Sun, Milky-way, Pulsars, Dark-matter, Radio Galaxies, Astrobiology - to Quasars, Cosmic Microwave Radiation, Galaxy Clusters, Cosmology and Big-bang theory.

During the winter school, the participants visited the sites of Giant Metrewave Radio Telescope (GMRT), operated by NCRA/TIFR and IUCAA's 2 m optical telescope facility at the Girawali Observatory near Pune. The programme exposed the young students to working of these instruments and excitement of doing astronomy with large telescopes. Throughout the school, the students showed tremendous enthusiasm and curiosity for learning new subjects, and they freely interacted among themselves and with faculty members in several well-planned informal discussion sessions (the 'Kattas'). Moreover, they prepared and presented their own colourful posters on various interesting topics in Physics and Astronomy. The best teams received handsome prizes. The School was coordinated by Joydeep Bagchi (IUCAA) and Bhal Chandra Joshi (NCRA/TIFR).

Public Outreach Programme

School Students' Summer Programme - 2009

School Students engaged in various activities

The annual School Students' Summer Programme was held from April 20 to May 29, 2009. Thirty students of class VIII and IX were invited to work on a project at IUCAA. During the period, starting every Monday, teams of 2-6 students were guided on scientific projects by volunteering scientists. In the spirit of true research, the students and guides worked together unfettered by set syllabus and time schedules. The students were given access to the library and the facilities of Science Exploratorium - the Muktangan Vidnyaan Shodhika, like the library, computer section and workshop. To give a finishing to their project, on the last working day of every batch, the student teams made presentations about the work they did during the week and submitted a report. This year the students carried out projects under the supervision of Dipankar Bhattacharya, Jayant Narlikar, Gaurang Mahajan, and Samir Dhurde.

The projects were diverse, covering wide range of topics, from optics to geo-synchronous satellites to soil-testing of IUCAA. Some students estimated the latitudes of various places seeing the IUCAA Foucault pendulum. A team made a collection of soil samples around IUCAA to find out various facts about geology and suggested changes in soil acidity of Newtons Apple tree in their report. Others studied the laws of optics and delved into calculus before they do it at school. Besides the team project, the students also had time for joint activities at MVS such as solving puzzles, making scientific toys, exploring the IUCAA Science Park and the new Organic Waste Converter Plant, etc.

The United Nations' (UN) 62nd General Assembly proclaimed that the year 2009 be celebrated as the International Year of Astronomy (IYA - 2009) based on an initiative by the International Astronomical Union (IAU) and UNESCO. Ranjeev Misra, Head Public Outreach Programme, IUCAA, was announced as the Single Point of Contact for India. As was reported in the last annual report, the Outreach Programme hand planned a series of activities and executed those to celebrate the IYA - 2009. A national website was set up for the information exchange and was updated periodically. A part of this report is a continuation of executed activities which were reported as planned or proposed in the annual report for 2008 - 09.

IYA Astronomical Diary

The IYA Astronomical Diary was conceived and directed by J. V. Narlikar and T. Padmanabhan. The diary was collated and designed by Samir Dhurde. It was produced on behalf of IUCAA as a part of its public outreach programme and was welcomed equally by amateur and professional astronomers.

The diary contained 53 weekly pages of well-researched information related to astronomy supplemented by a compilation of coloured photographs and diagrams. An effort has been made to highlight events happening in the respective weeks but it also includes details about other important Discoveries, Scientists and some Astro-facts. Beautiful sky maps prepared by Arvind Paranjpye were provided.

Even though the diary has been dated 2009, it contained a wealth of information and has been a collectors item. The diary has been kept online too and the link is available at http : //www. iucaa.ernet.in/~scipop/Literature/iyadiary. html.

Telescope making workshops for school students

As a part of activities related to IYA - 2009, IUCAA conducted small refractive telescope making workshops in various institutions, university departments and colleges in India. In all, there were 13 workshops, of which 10 were conducted between April 09 and Jan 10.

Refracting telescopes (with 45 mm diameter achromatic objective), nicknamed Galilioscope ++ were made during these workshops by high school and junior college students using kits provided by IUCAA.

About 20 of these were made by participants of each workshop, working in teams of two students each. The telescopes have been used successfully in observations, and it is very interesting that the views that students get through these telescopes are very similar to the observations made by Galileo using telescopes that he had made himself 400 years ago.

IUCAA, in association with universities and other institutions has conducted telescope and spectroscopy workshops for the school students. In the workshop, about 20 groups of two students and a teacher were invited to make a simple Galileoscope, using 45 mm achromatic lens, ramsdon eyepiece, and a 45 degree mirror. Galileoscope++ (two plus indicate that the telescope has an achromatic lens, a 45 degree mirror and is on a stand).

The workshops conducted were as follows.
April 1-15 : In association with the Physics Department, Utkal University, Bhubaneswar. The workshop was coordinated by Pushpa Khare.
April 11-12 : In association with the Indian Institute of Science Education and Research, Kolkata. The workshop was coordinated by Narayan Banerjee.
April 20-21 : In association with the IRC, Department of Physics, Cochin University of Science and Technology, Kochi. The workshop was coordinated by V. C. Kuriakose.
May 24-25 : In association with the Physics Department, North Bengal University, conducted at Silchar. The workshop was coordinated by B. C. Paul.

G++ Galileoscope and Spectroscopy Workshops

IUCAA International Year of Astronomy Programmes
G++ Galileoscope and Spectroscopy Workshops

IUCAA Public Outreach cell continued it's G++ Galileoscope programme at IRC Udaipur (August 25-26), Saurashtra University (September 12 -13), Gangtok, Sikkim (September 21-22), and North Bengal Science Centre (September 23).

The Udaipur workshop was conducted at the historical town of Nathdwara, about 50 km north of Udaipur, during August 25-26, 2009, in collaboration with Shrinathji Institute of Technology and Engineering (SITE), Udaipur. There were 22 registered schools from Rajasthan, Gujarat, and Madhya Pradesh, with three participants from each school (one lecturer and two students). Faculty members, research scholars, M. Sc. students, and other interested persons in astronomy also attended this workshop. The workshop was inaugurated by Onkar Singh. The inaugural talk was delivered by P. C. Agrawal, TIFR, Mumbai on Visphot Bhara Brihmand. Other talks were given by Arvind Paranjpye, IUCAA; S. N. A. Jaaffrey, Department of Physics, Mohanlal Sukhadia Uuniversity, Udaipur. The training to assemble the telescope and seeing sky was given by Arvind Paranjpye.

The workshop at Saurashtra University, Rajkot was requested by K. N. Iyer, Department of Physics, coordinated by Neelish Rana, and was held at Shri. O. V. Sheth Regional Community Science Centre, Rajkot. Tushar Purohit (MViSA volunteer) and Shrirang conducted the workshop, in which 23 telescopes were made by the participants. This workshop was first of its kind held at the centre, which carries out many activities to promote amateur astronomy. All the telescopes were tested on the same night, where everyone was very excited to view Jupiter, which was at a very favourable location.

Kanti Jotania, of M. S. University of Baroda and IUCAA Associate, delivered a popular lecture on Black Holes in Gujarati, and Shakuntala Nene gave a lecture on Spectroscopy, which was followed by a demonstration of spectroscopy using a compact disc by Srirang. The participants included individuals, interested in astronomy, university students, and school students accompanied by their teachers.

The Gangtok workshop was organised by Rabin Chettri, an IUCAA Associate from the Government College Sikkim, and Ivan Lepcha, PNG School, Gangtok. The workshop was supported by the DST, Sikkim, and the venue was the Sikkim Science Centre. Twenty enthusiastic schools and amateur clubs from various parts of the state of Sikkim participated in the one-day workshop on September 21, 2009. The workshop was conducted by Samir Dhurde from IUCAA and preceded by a talk on Astronomy and Telescopes.

Samir also carried out a training on how to read sky maps for astronomical observations. Free constellation charts were distributed to all students. Following this, the local teachers have shown interest in starting astronomy clubs in the respective schools.

The North Bengal Science Centre in Siliguri, West Bengal, hosted an Astronomy Popularisation programme on September 23, 2009, with an emphasis on Spectroscopy. The event focussed on getting students of classes 10, 11, and 12 interested in basic astronomy. A talk titled Fingerprinting Astronomical Bodies and a hands on CD-spectroscope making workshop was conducted by Samir Dhurde. The 70 participants from 20 different schools and junior colleges learnt the basics of spectroscopy and made their own spectroscope to observe various light sources.

Introductory Workshop on Optical Observations and Data Analysis

An Introductory Workshop on Optical Observations and Data Analysis was held during June 9-10, 2009 at Vigyan Bhavan, Mohanlal Sukhadia University, Udaipur, where IRC is located in a separate block. There were 37 participants, including faculty members, research scholars, M. Sc. students and interested persons in Astronomy. The workshop was inaugurated by P. Venkatakrishnan, Director of Udaipur Solar Observatory. He delivered the inaugural talk on activities of Udaipur Solar Observatory and scope of the optical observations and data analysis. The other speakers were Arvind Paranjpye, IUCAA, Pune and S. N. A. Jaaffrey, Coordinator of IRC, Visiting Associate of IUCAA, Department of Physics, Mohanlal Sukhadia University, Udaipur.

The main theme of the workshop was to expose the participants to optical observations, both stellar and solar, and also to promote the thrust and interest in Astronomy and Astrophysics. The participants were also given an opportunity to operate a telescope of six inch (donated by IUCAA, Pune, to IRC, Udaipur). They were also taught to couple the telescope with computer, and how to take good quality pictures of celestial objects for their observations in optical wavelength. A brief description was also given on how to identify stellar objects and their positions in sky. This activity helped much in popularizing Astronomy among the people of Udaipur regional colleges and schools.

On the second day, hands on practice was given to participants, in which they tried to calculate some physical observables of observed stellar objects.
During the workshop, the following animation movies were screened :
(a) Cosmic collisions, and
(b) Chandra : The journey of a star.

A public outreach programme was also organized as a part of workshop. The college, school students and other interested people were invited for sky gazing. A six inch telescope was used to observe the planet Saturn and its rings. Newspapers, Rajasthan Patrika, and Dainik Bhaskar, gave enough coverage of this workshop for the people to know about the facilities available at recently opened IRC at Udaipur, and kind of research work which can be pursued by research students.

Scientific Toy Making and Telescope and Spectroscopy Workshop

Ashok Rupner and Samir Dhurde have conducted Scientific Toy making and Telescope and during October 26 - 28, 2009 Spectroscopy workshop for the educators at Priyadarshini Planetarium, Thiruvananathapuram, Kerala. There were about 20 participants. They also did a telescope usage training session and conducted a sky observation in Tirunelvelli, Tamilnadu.

V. C. Kuriakose, IRC Cochin, invited Arvind Paranjpye to give a series of public talks on Astronomy. These talks were delivered at St. Teresas College and Maharajas college, Ernakulam; Newman College, Thodupuzha; Alphonsa College, Palai; Catholicate College, Pathanamathitta; St Thomas College, Kozhencherry and Devamatha College, Kuraviangad. Paranjpye has alsogiven a talk on doing astronomical observations using Small telescopes at Priyadarshini Planetarium, Thiruvananathapuram.

The second last workshop in this series was conducted at Shri Guru Ram Rai (PG) College, Dehradoon, by Paranjpye during November 14 - 15, 2009. The workshop was coordinated by A P Singh, Principal and Dinesh Singh, Sr. Lecturer of the college. There were 20 schools that participated in the workshop by sending two students and one teacher from each school.

Like other workshops, students made their telescopes and those were handed over to them at the conclusion of the workshop. They also viewed the planet Jupiter and its moons, which were available in the sky at dusk, just the way Galileo had seen 400 years ago.

Telescope Making Workshop at Raipur

On the occasion of the International Year of Astronomy- 2009, the last workshop on telescope making was conducted at Raipur, during January 6 -7, 2010. The intiative was taken by S. K. Pandey, Vice Chancellor, of Pt. Ravishankar Shukla University, Raipur and coordinated by Alok Sharma of State

Pictures from Bhubaneswar, Kolkata, Kochi and Silchar

Participants of the Telescope making workshop at Pt. Ravishankar Shukla University, Raipur

Council of Educational Research and Training (SCERT), Raipur, Chhattisgarh.

S. K. Pandey inaugurated the workshop and gave the keynote address. In all, 20 telescopes were made by 20 pairs of students and their accompanying teachers. During these days, Jupiter was visible above the western horizon, and it was very excited feeling for the students to recall that almost exactly 400 years ago, Galileo had pointed his telescope in the direction of Jupiter. All the students and participating teachers made cardboard spectroscopes with CD/DVD as dispersing element. Jyoti Chakaraborty of SCERT coordinated the programme.

R. K. Thakur, former Vice Chancellor, of the same University took a lively one hour and a half session, in which he narrated stories about astronomers and physicists. Arvind Ranade of Vigyan Prasar, New Delhi, participated in the workshop and gave a popular talk, and conducted a quiz competition.

Telescope Making Workshop at Thiruvananthapuram

IUCAA has conducted a telescope making workshop for the students of the Indian Institute for Space Science Technology, (IIST), Thiruvananthapuram, during February 1 - 6, 2010. There were about 45 participants, who made 24 reflecting telescopes with 100 mm primary mirror on altazimuth mount.

A prototype of reflecting telescope with 100 mm diameter mirror was developed at IUCAA in October/ November 2009. It has taken about 20 man days to make a standard amateur telescope with 150 mm (6 inch) diameter. Such a telescope, initially, has been used for observing planets and bright objects. Keeping this in mind, it was thought that a telescope with 100 mm mirror would ideally suit as beginner's telescope, that would take less amount of time and proportionately less cost. Just as this project was coming close to its conclusion, IIST explored the

Participants of the Telescope Making Workshop

possibility with IUCAA for conducting a telescope making workshop for their students. This workshop was conducted as part of Conscientia 2010, the annual TechFest of IIST.

The workshop was started with Arvind Paranjpye giving a lecture and demonstration on astronomical telescope, and the telescope that the students were going to make. During the workshop, the students have grounded the glass blanks to get sagitta sufficient for *f* ratios between 8 and 10. No stringent requirement was placed on exact focal length. Mirrors were then polished and figured. In parallel, telescope mounts were made. Finally, the mirrors were silvered by chemical precipitation. Using these telescopes, on the night of February 5, students could see Orion nebula and Pleiades through their own telescope.

During the five days workshop, many interactive sessions were conducted to clear the doubts regarding the making and uses of the telescope.

The workshop was coordinated by Anandmayee Tej, and conducted by Arvind Paranjpye. Tushar Purohit and Makarand Paranjpye supplied the materials and assistance.

On the AIR

All India Radio, Pune, with IUCAA, started a special IYA monthly astronomy programme of 30 minutes duration. During the clear-sky period, listeners are invited to join IUCAA through a live sky-show, but from their own roof tops. During the cloudy period, discussion and live phone-in sessions on varied topics such as careers in Astronomy and Astrophysics, Eclipses, etc. were carried out. Arvind Paranjpye has been conducting the programme with inputs from Samir Dhurde on sky watching. The All India Radio, Pune, reaches out to people in about 200 kilometers radius on their AM channel. The programme dates were announced well in advance and the star maps for the night of broadcast were distributed.

Public visit to IUCAA Girawali Observatory

From time to time, IUCAA has been receiving requests to visit IUCAA Girawali Observatory (IGO) from citizens of Pune and a few from far off places. To honour their request, IUCAA has started "I Go to IGO programme". These visits have been coordinated with the IGO staff and handled through the Public Outreach Programme by Arvind Paranjpye.

Every visit consists of about 25 people. Visitors are introduced to the state-of-the-art telescope and its functions.

Mobile Planetarium Activities

Sixteen Planetarium Training sessions for teachers and volunteers were carried out by Samir Dhurde. These were aimed to encourage independent use of the planetarium kits by enthusiastic educators. Many regular events have been carried out by various schools and community development organisations.

As a special mention of this kind of activities, IUCAA has loaned the inflatable and mobile Planetarium for four months to Maharashtra Andhashradha Nirmulan Samiti (M-ANIS) (an organization of rational thinkers working towards the eradication of superstitions among common public) on a request from its President, Narendra Dabholkar. The request was granted by the director and the planetarium was taken to scores of different talukas of the state. In course of this, M-ANIS made prior arrangements with various schools for conducting the planetarium shows. A full time, IUCAA-trained volunteer accompanied the planetarium. The van also carried a small telescope, and depending upon the time and clarity of the sky, sky shows were also carried out.

Two booklets "Postcardatun Vidnyan" (Science Through Postcards) by Jayant V. Narlikar and "Chala Karuya Akashdarshan" (Let us observe the sky) by Arvind Paranjpye have also been made available for the students attending the planetarium shows.

Astronomy Workshop for school teachers from Ambegaon Taluka

A two day Astronomy Workshop was conducted for the teachers of primary schools from Ambegaon Taluka at the Science Centre of IUCAA during December 22 - 23, 2009. This was all women's workshop, in which 24 teachers have participated. The theme of the workshop was to discuss teaching methods in astronomy, taught in their schools. The teachers have also carried out various hands-on activities, such as finding north-south direction by observing the shadow of a vertical Gnomon. On the night of December 22, a live sky show was conducted on All India Radio, Pune Station, with the teachers participating in this programme. Arvind Paranjpye conducted the workshop with inputs from Samir Dhurde on sky watching. Vidula Mahiskar and Ashok Rupner have done science teaching aids demonstrations.

NATIONAL SCIENCE DAY CELEBRATIONS - 2010

The National Science Day celebrations - 2010 were extended this year beyond the campus of IUCAA, Pune. Samir Dhurde and Ashok Rupner carried out hands-on science and astronomy activities at Panditrao Agashe School, Pune, on February 17. Science lectures were given by Dipankar Bhattacharya (at Panditrao Agashe School on February 22) and by A. N. Ramaprakash (at Indian Institute for Aeronautical Engineering and Information Technology, Pune on February 26).

In IUCAA, Pune Campus, the school students competitions were conducted on February 27. About 250 students of class VIII and IX participated in drawing, essay and quiz competitions. Amit Dhakulkar from Homi Bhabha Centre for Science Education, Mumbai, interacted with the teachers about experiments with science teaching. Arvind Gupta talked with the students and teachers on doing simple science toys using discarded materials.

On February 28, general public started gathering outside IUCAA, Pune campus, well before the scheduled start of Open Day at 11 : 00 a. m. that prompted us to open the gates at 10 : 45 a. m.

Scientific Toys were demonstrated by the students from Loyola and Vidyapeeth High Schools, Pune in the science park area, out side the Chandrasekhar Auditorium.

Continuous demonstrations on Virtual Observatory, World Wide Telescope and Google sky were conducted by Tushar C. Agrawal and Sibasish Laha in IUCAA Lecture Hall Bhaskara 1.

Series of films on astronomical topics were screened in Bhaskara 3. It started with Vijay Mohan giving introduction to IUCAA Girawali Observatory, followed by series of video clips of the observatory.

In the foyer between Bhaksara 2 and Bhaskara 3, introduction to general astronomy, and specifically IUCAA related research work was displayed with the help of eye-catching colourful posters. Faculty and students were present at the poster exhibition to answer queries of the visitors.

Three architect student volunteers explained IUCAA architecture with the help of scaled down model of IUCAA buildings.

In and outside Bhaskara 2, Radio Astronomy related experiments and observations were set up. A simple DIY Lissajues figure was also shown by the Instrumentation Laboratory group.

Outside the Muktangan Vidnyan Shodhika (MVS), a poster exhibition of astronomical images was setup along with an astronomical telescope and water rocket demonstration.

A special workshop on making a simple spectroscope using CD or DVD was organized in the MVS. It was announced that those interested in participating in this workshop may bring one discarded CD or DVD. In all, 600 people made their own spectroscope.

All these exhibits and demonstrations were conducted through out the day. In addition, there were following scheduled events.

Ajit Kembhavi, Moumita Aich and Sanil Unnikrishnan gave 30 minutes talk each on astronomical topics. Jayant Narlikar and T. Padmanabhan answered questions from visitors.

The day ended with lectures on science Nobel Prizes. A. N. Ramaprakash talked on 2009 Nobel Prize in Physics, and C. Suresh from National Chemical Laboratory, Pune, gave a talk on 2009 Nobel Prize in Chemistry.

Due to bright full moon light on the night of February 28, this year's night sky show was cancelled.

National Science Day programme at Girawali, Ambegaon Taluka

As a part of the on going rural outreach programme, IUCAA also conducted competitions for the school students of Ambegaon Taluka.

Essay and drawing competitions were conducted in the premises of the IUCAA Girawali Observatory (IGO) on March 6, 2010. After the competitions, the students and teachers visited IUCAA's state-of-art 2 m telescope. The quiz competitions were held in the New English School, Landewadi, on March 15, 2010. While the quiz elimination round was conducted for the students, teachers solved a science crossword.

The Vidya Vikas Mandir, Awasari Budruk, has won prizes in all the three events and the results are given in the following page. These students would be given KSVS Narasimhan Prize.

Results of various competitions held in Ambegaon Taluka

Quiz competition	
1st prize	: Chinmay Mandale, Sahil Inamdar and Rutwik Khandeshe from New English School, Landewadi.
2nd prize	: Shubham Hinge, Aniket Chavan and Triveni Shinde from Vidya Vikas Mandir, Awasari Budruk.
3rd prize	: Akash Khinvasara, Snehal Shete and Rahul Kanawade, from Shivaji D. Adhalrao P. Vidyalaya, Landewadi.
Essay (Marathi)	
1st prize	: Amruta Kokane from Sant Dnyaneshwar Vidyalaya, Chas.
2nd prize	: Shubham Hinge from Vidya Vikas Mandir, Awasari Budruk.
3rd prize	: Raviraj Mathe from Jagdishchandra Mahindra High School, Chincholi, Khurd.
Drawing	
1st prize	: Nishighandha Shete from Vidya Vikas Mandir, Awasari Budruk.
2nd prize	: Pallavi Sutar from New English School, Landewadi.
3rd prize	: Kameshwari Divekar from Hutatma Babu Genu Vidyalaya, Mahalunge Padwal, *and* Swapnil Jaid from Shri. Navkund Madhyamik Vidyalaya, Pargaon Peth.

The list of the winners in various competitions held in IUCAA, Pune campus, is given below.

Quiz competition		
1st prize	:	Abhinava Vidyalaya English Medium High School, represented by Yash Raghunandan Dixit, Devdutta Pradeep Phatak, and Tanmayan Prabodh Pande.
2nd prize	:	Bharatiya Vidya Bhavan Sulochana Natu Vidya Mandir, represented by Pinak Vidyasagar Ghate, Kedar Bhalchandra Chaudhari, and Adwait Vilas Pawgi.
3rd prize	:	D. A. V. Public School, represented by Sameer Suri, Sourabh Badane, and Gautam S. P.
Essay (English)		
1st prize	:	Ashay Navnath Ghogare, St. Vincent's High School.
2nd prize	:	No prize was given.
Honourable mention	:	Somarth Kallurya, Abhinava Vidyalaya High School; Ashish Kumar Singh, Army School, B. E. G., Kirkee; Moumita Subhasis Pal, DSK School.
Essay (Marathi)		
1st prize	:	Kalyani Sunil Marathe, Jnana Pabodhini Prashala.
2nd prize	:	Rutuja Digamber Karanjkar, Mahilashram High School.
Honourable mention	:	Aditya Balwant Patil, New English School.
Drawing		
1st prize	:	Mayur Balasaheb Shinde, Modern High School.
2nd prize	:	Karishma Deshpande, Jai Hind High School.
3rd prize	:	Vaidehi Supalkar, Delhi Public School.

T. Padmanabhan, Dean, Core Academic Programmes, IUCAA, gave away the prizes.

Popular Talks and Articles by IUCAA Members

(a) Popular talks :

Bhaswati Bhattacharyya

Pulsars - Light houses in sky, National Science Day, IUCAA, February 28.

Dipankar Bhattacharya

Origin of the Moon, Panditrao Agashe School, Pune, February 22, 2010

Gulab Chand Dewangan

The Universe in X-rays, I^2 IT, Hinjewadi, Pune, INSPIRE project, January 21.

Ranjan Gupta

Astronomical telescopes from Galileo till today, Sukanta Academy, Tripura State Council for Science and Technology, Agartala, Tripura, July 6, 2009.

Career opportunities in astronomy, Junior College Science students Agartala, July 7, 2009

Artificial neural networks — Applications to astronomy, SIES College, Nerul, Navi Mumbai, January 19, 2010.

New astronomical telescopes and opportunities, SIES College, Nerul, Navi Mumbai, January 19, 2010.

Ajit Kembhavi

Galileo to Einstein, Miraj Vidyarthi Sangh, Miraj, May 19, 2009.

From Galileo to Einstein-A Journey over 400 Years, Panjab University, Chandigarh, November 19, 2009.

From Galileo to Einstein-A Journey over 400 Years, "Vedha Vishwacha" (Astronomy Conference 2009), Thane, December 13, 2009.

Careers in Astronomy in India, Astronomy in India-Seminar (IYA), NIO, Goa, December 12, 2009.

The inspiration from Galileo, Innovation in Science Pursuit for Inspired Research (INSPIRE), Isquare IT, Pune, December 28, 2009.

The New Planets : Worlds outside the solar system?, Astronomy Exhibition 'Surprises of the Cosmos', Centre for Science Education and Communication, University of Delhi, February 9, 2010.

Navya Grahancha Shodh, Science Day, IUCAA, Pune, February 28, 2010.

Aaple wa Baherche Graha, Science Day, Giant Metrewave Radio Telescope, Khodad, March 1, 2010.

Ranjeev Misra

Black holes in the universe, Tezpur University, Tezpur, Assam, October 2009.

Black holes in the universe, Yashavantrao Chavan Institute of Science, Satara, December 2009.

Vijay Mohan

Solar eclipses, Pt. Ravishankar University, Raipur, July 18, 2009.

J. V. Narlikar

Searches for life in the universe, Kerala State Science and Technology Museum, Thiruvananthapuram, April 2, 2009.

Khagolshastracha abhyas ka karayacha? (Why study astronomy?) (in Marathi), National Centre for Radio Astrophysics, Pune at the Butte Patil Vidyalaya, Junnar, April 18, 2009.

Savarkar aani vaidnyanik drushtikon (Savarkar and the scientific temper) (in Marathi), a lecture organized by the Swatantryaveer Savarkar Rashtriya Smarak, Mumbai at IUCAA, Pune, May 15, 2009.

The IUCAA Story : The trials, tribulations and satisfaction in building a scientific institution, INFOSYS, Pune, June 4, 2009.

The wonderful world of astronomy : a personal tribute to International Year of Astronomy, India International Centre, New Delhi, June 23, 2009.

The role of science fiction in the present age of science, Indian Institute of Technology, Kanpur, June 24, 2009.

The amazing world of astronomy, St. Joseph's College, Nainital, June 27, 2009.

Searches for micro-life in the Earth's atmosphere, Tata Motors Ltd., Pune, July 29, 2009.

Searches for micro-life in the Earth's atmosphere, a talk organized by the Association of Friends of Astronomy at Kala Academy Auditorium, Goa, October 11, 2009.

Khagol vidnyan ka shikave? (Why study astronomy?) (in Marathi), Professor Dr. B. N. Kulkarni Charitable Trust, Sangli, October 31, 2009.

Heritage of Indian astronomy and its relevance today, Bharatiya Vidya Bhavan, Pune, November 6, 2009.

Antaralatil jeevjantu, (Searches for micro-life in the Earth's atmosphere) (in Marathi), Akshardhara, Pune, November 12, 2009.

Why study astronomy?, Second Saturday Lecture and Demonstration Programme, IUCAA, Pune, November 14, 2009.

Khagol vigyan ka adbhoot vishwa (The amazing world of astronomy) (in Hindi), Dollarrai Mankad Endowment Lecture, Saurashtra University, Rajkot, November 28, 2009.

Vishwat aapan ekate aahot ka? (Are we alone in the universe?) (in Marathi), 'Swanand' – Senior Citizen Forum, Pune, January 15, 2010.

Astronomical observing from the past to the present, General Optics (Asia) Ltd., Pondicherry, February 12, 2010.

Khagol vidyan ki mahatta (Important aspects of astronomy) (in Hindi), Banaras Hindu University, Varanasi, February 20, 2010.

The amazing world of astronomy, Rajiv Gandhi Memorial Lecture at the Rajiv Gandhi Science Centre, Mauritius, March 2, 2010.

T. Padmanabhan

Understanding gravity, CUSAT, Cochin, January 29, 2010.

Understanding our universe : Status and Future, Indian Institute of Space Science and Technology, Techfest Trivandrum, March 5, 2010.

A glimpse of relativity, IISER, Thiruvananthapuram, August 3, 2010.

Surajit Paul

21-cm spin-flip line of neutral hydrogen, Winter School on Radio Astronomy December 25, 2010.

A. N. Ramaprakash

What is 'Nobel' about Gigabyte downloads and Megapixel cameras? Nobel Lecture, IUCAA Science Day, February 28, 2010.

Tarun Souradeep

Cosmic clues in the cosmic microwave background, National Workshop on Astronomy, University of Kashmir, November 3, 2009.

Cosmic microwave background, 'Unfolding The Universe', R. D. National College, Mumbai, February 5, 2010.

(b) Popular Articles :

J. V. Narlikar

Narlikar, J. V. (2009) *Issac Newton : Who started it all*, (Co-authored with T. Padmanabhan), DNA, April 6.

– (2009) *A statistical test of astrology*, (Co-authored with Sudhakar Kunte, Narendra Dabholkar and Prakash Ghatpande), Current Science, **96**, 5, 641.

– (2009) *Albert Einstein and bending of light*, (Co-authored with T. Padmanabhan), DNA, April 13.

– (2009) *Stars brighten and stars fade*, (Co-authored with T. Padmanabhan), DNA, April 21.

– (2009) *Hubble vision*, (Co-authored with T. Padmanabhan), (DNA, April 27)

– (2009) *Plenty of moons*, (Co-authored with T. Padmanabhan), DNA, May 4.

– (2009) *Spheres of the master*, (Heritage India, **2**, 2, 90)

– (2009) *Various observatories in India*, (Co-authored with T. Padmanabhan), DNA, May 11.

– (2009) *Why study astronomy?*, (Dream 2047, **11**, 8, 38)

– (2009) *A law that isn't*, (Co-authored with T. Padmanabhan), DNA, May 18.

- (2009) *The starry episodes of lunar occultations and quasars*, (Co-authored with T. Padmanabhan), DNA, May 25.
- (2009) *The transit of Venus*, (Co-authored with T. Padmanabhan), DNA, June 1.
- (2009) *James Maxwell (1831 – 1879)*, (Co-authored with T. Padmanabhan), DNA, June 8.
- (2009) *The beginning of radio astronomy*, (Co-authored with T. Padmanabhan), DNA, June 15.
- (2009) *Eratosthenes and the radius of the Earth*, (Co-authored with T. Padmanabhan), DNA, June 22.
- (2009) *A historic explosion*, (Co-authored with T. Padmanabhan), DNA, June 29.
- (2009) *The ever changing Moon*, (Co-authored with T. Padmanabhan), DNA, July 6.
- (2009) *The culture of science*, Jijnasa, 17.
- (2009) *Opposition to new ideas in science*, Jijnasa, 35.
- (2009) *Total solar eclipse*, (Co-authored with T. Padmanabhan), DNA, July 13.
- (2009) *The giant leap for mankind*, (Co-authored with T. Padmanabhan), DNA, July 20.
- (2009) *Astronomical times*, (Co-authored with T. Padmanabhan), DNA, July 27.
- (2009) *Tracking the heavens*, Heritage India, **2**, 3, 83.
- (2009) *Eris : Largest known dwarf planet*, (Co-authored with T. Padmanabhan), DNA, August 3.
- (2009) *Remembering MWC*, (Professor M. W. Chiplonkar Centenary Souvenir) 27.
- (2009) *Vainu Bappu and this comet*, (Co-authored with T. Padmanabhan), DNA, August 10.
- (2009) *The discovery of Helium*, (Co-authored with T. Padmanabhan), DNA, August 17.
- (2009) *Why is Pluto not a planet?*, (Co-authored with T. Padmanabhan), DNA, August 24.
- (2009) *First astronomical use of a telescope*, (Co-authored with T. Padmanabhan), DNA, August 31.
- (2009) *Catching and classifying Ceres*, (Co-authored with T. Padmanabhan), DNA, September 7.
- (2009) *Discovery of Neptune : A triumph for science*, (Co-authored with T. Padmanabhan), DNA, September 14.
- (2009) *Unequal equinoxes*, (Co-authored with T. Padmanabhan), DNA, September 21.
- (2009) *The holy grail of cosmology*, (Co-authored with T. Padmanabhan), DNA, September 28.
- (2009) *Meghnad Saha and his equation*, (Co-authored with T. Padmanabhan), DNA, October 5.
- (2009) *Subrahmanyan Chandrasekhar & white dwarfs*, (Co-authored with T. Padmanabhan), DNA, October 12.
- (2009) *The first surface image of planet Venus*, (Co-authored with T. Padmanabhan), DNA, October 19.
- (2009) *Searches for microlife in the Earth's atmosphere*, Via Lactea, October.
- (2009) *The H-R diagram and the life of a star*, (Co-authored with T. Padmanabhan), DNA, October 25.
- (2009) *Eddington and the bending of light*, (Co-authored with T. Padmanabhan), DNA, November 2.
- *(2009) C. V. Raman and the Raman effect, (Co-authored with T. Padmanabhan), DNA, November 9.*
- (2009) *The catastrophic hole*, (translated by Vijay Rale), Chhatra Prabodhan, Diwali Issue, 5.
- (2009) *Making the universe move*, (Co-authored with T. Padmanabhan), DNA, November 16.
- (2009) *The galactic neighbours*, (Co-authored with T. Padmanabhan), DNA, November 23.
- (2009) *Gamma-ray bursts*, (Co-authored with T. Padmanabhan), DNA, November 30.
- (2009) *Special areas scientific research : advancing the cause in India*, The Hindu, December 3.
- (2009) *The cosmic web*, (Co-authored with T. Padmanabhan), DNA, December 14.

- (2009) *A shower of light in the skies*, (Co-authored with T. Padmanabhan), DNA, December 14.
- (2009) *Jantar Mantar and its yantras*, (Co-authored with T. Padmanabhan), DNA, December 21.
- (2009) *Why study astronomy?*, (Co-authored with T. Padmanabhan), DNA, December 28.
- (2009) *Tools for science education*, Science Communication, 108.
- (2009) *Khagol vidyan ka adhyayan kisliye?*, (in Hindi) [Why study astronomy?], Dream 2047, **11**, 8, 7.
- (2009) *Phalit jyotish ki prayogik jaanch*, (in Hindi) [A statistical test of astrology], Srote, June.
- (2009) *Tari mi alpapathit*, (in Marathi) [Still I am poorly read], Granthanchya Sahavasat, 61.
- (2009) *Nile akash … saptarangi indradhanushya ani kalya akashat soneri surya … kashi ghadate hi jadu?*, (in Marathi) [Why is the sky blue?], Friend, No. 2, 4.
- (2009) *Khagol vidyan ka shikave?* (in Marathi) [Why study astronomy?], Chhatra Prabodhan, May.
- (2009) *Adbhut grahamala*, (in Marathi) [Wonderful world of planets], Friend, No. 3, 4.
- (2009) Mazi kalpak Aai, (in Marathi) [My imaginative mother], Panchavati Patrika, May.
- (2009) *Galileo ne ghadavun aanaleli kranti* (in Marathi) [The revolution brought about by Galileo], Souvenir of the Agarkar High School and Junior College, 17.
- (2009) *Olakh grahamalechi* (in Marathi) [Getting acquainted with our planetary system], Friend, No. 4, 4.
- (2009) *Vidnyan sanshodhanatil uttejana* (in Marathi) [The experiment of scientific research], Vidnyanyatri, 83.
- (2009) *Udatya tabakadyanche rahasya* (in Marathi) [The mystery of flying saucers], Learn More, October 15, 5.
- (2009) *Ujavya sondecha ganapati* (in Marathi) [Ujavya sondecha ganapati], Vedhak vidnyankatha, 88.
- (2009) *Putravati bhava* (in Marathi) [Putravati bhava], Vedhak vidnyankatha, 106.
- (2009) *Chidreshavanartha* (in Marathi) [The catastrophic hole], Chhatra Prabodhan, Diwali Issue, 5.
- (2009) *Khadkat rutalele mangalavaril jeevashma!* (in Marathi) [Fossilised life in martial meteorites], Learn More, December 15, 6.
- (2009) *Kalpanasharadiyam* (in Sanskrit) [About Kalpana and Sharad], Gunjaravha, 11.
- (2010) *Nobelche mankari Subramanyan Chandrasekhar* (in Marathi) [Nobel Laureate Subramanyan Chandrasekhar], Learn More, January 15, 6.
- (2010) *Vidnyan ani me : Me vaidnyanik kasa zalo?* (in Marathi) [Science and me : How I became a scientist?], Jeevan Shikshan, February issue, 12.
- (2010) *Vidnyan ani me : Me vaidnyanik kasa zalo?* (in Marathi) [Science and me : How I became a scientist?], Dnyanda, 25.

(c) Radio/TV Programmes

Ajit Kembhavi

IUCAA's Twenty Years, AIR, Under Akashdarshan Programme, August 20.

J. V. Narlikar

Navalaeecha Khagol (in Marathi), All India Radio, February 7.

FACILITIES

(1) Computing Facility

The 2009-2010 academic year was a fruitful one for the computing facility related activities.

High Performance Computing (HPC) plays a crucial role in solving very many fundamental problems encountered in Astrophysics. The pulsar survey at intermediate galactic latitudes was undertaken in mid 2009, with a view to enhance the known pulsar population by taking advantage of capabilities at GMRT. This project required an extensive computational exercise. In May 2009, IUCAA expanded its HPC facility with an additional independent cluster comprising of 32 node (dual Quad-Core AMD Opteron(tm) Processor 2384 @ 2.7 Ghz (32 * 2 * 4 = 256 cores)) blade servers, 1024 GB RAM, 20 TB SFS (Scalable File system) storage, which offered 2 Gbps I/O bandwidth, scalability and reliability. The independent clusters cetus (128 cores) and pleiades (256 cores) were then integrated via LSF multicluster software to simplify management and usability.

IUCAA's computing facility was instrumental in setting up a computing facility at six IRCs (IUCAA Resource Centres) for hosting widely used catalogues, data and application software relevant to Astronomy and Astrophysics. The process involved identification, procurement, installation and testing hardware and software. This took about 6 months from May-November 2009, to complete the process.

Computing facility was built in IUCAA 2more than 0 years ago to accommodate mostly users and a few stand alone servers. The procurement of blade server based HPC, three years ago, generated the need for a data centre. Effective data centre design has grown in complexity in the past few years, largely due to rapid advancements and changes in processor speed. The new data centre designed and commissioned in August 2009 at IUCAA by M/S Emerson, the leader in UPS and air conditioners, can accommodate 8 racks. Currently, it offers precision cooling to six racks with high density blade based HPC clusters, 80 TB storage, various blade servers that serve mirror sites, web service, email service and so on.

In December 2009, network auditing procedure was initiated to analyze the existing network. Subsequently, in February 2010, M/S Locuz carried out extensive network audit and penetration test in IUCAA network and submitted audit analysis report as well as recommendations, so as to make the network secure and easy to use.

As the nature and diversity of Internet threats grows more complex, the need for UTM (Unified Threat Management) became important. The principal advantages of UTM are simplicity, streamlined installation and use, and the ability to update all the security functions or programme concurrently. It also eliminates the need for systems administrators to maintain multiple security programmes over time. In January 2010, Sonicwall UTM was identified, after conducting a comprehensive study on various UTM products available in the market.

The IUCAA Computer Centre continues to upgrade itself with the state-of-the-art computing resources to cater to the needs of IUCAA users as well as IUCAA associates and visitors from the universities and institutions in India and abroad.

(2) Library and Publications

During this year, the IUCAA library added 202 books and 400 bound volumes to its existing collection, thereby, taking the total collection to 23,035. 127 journals were subscribed by the library. 203 books were added to the collection of the Muktangan Science Exploratory library.

The library has received 173 full-text article requests from 56 academics (including students), through e-mail/post/in-person, interlibrary loan requests for 09 books from 5 libraries and requests for 04 books from its users, which were acquired on interlibrary loan from FORSA libraries. 80 full-text articles were dispatched to academics availing the table of contents service.

The highlight of the year was the organization of the 6th Library and Information Services in Astronomy (LISA VI) conference (http://libibm.iucaa.ernet.in/conf/index.html) which was held during February 14-17, 2010 at IUCAA, Pune. Report on LISA VI may be found under the section "Scientific Meetings and Workshops".

IUCAA has full-fledged publications department that uses the latest technology and DTP software for preparing its publications like the Annual Report, Quarterly bulletin "Khagol", Posters, Academic Calendar, Conference Proceedings, etc.

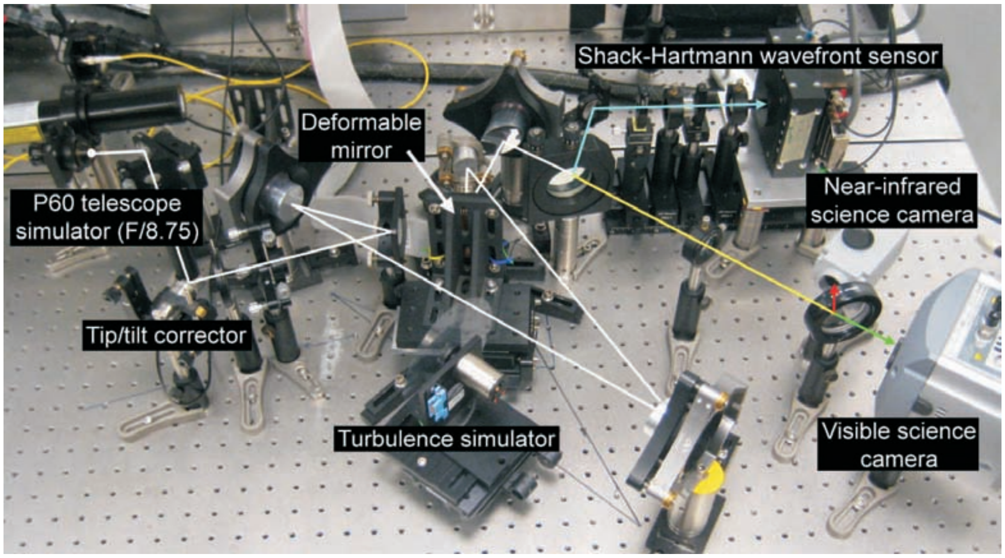


Figure 30: Figure shows components of RoboAO being set up and tested in the laboratory at Caltech

(3) Instrumentation Laboratory

IUCAA Instrumentation Laboratory, in tune with the vision that was projected in last year's report, has made progress in several key areas. Some facility enhancements have been completed, some more are being planned, two international collaborations are underway, some national level projects are in the early stages of development and there has been growth in human resources. Observatory operations, maintenance and upgrade activities continue.

The design centre, mentioned in last year's report, for carrying out work with AutoCAD, OrCAD, Zemax, RSLogix, PanelBuilder, etc. has already been set up. A Class 10000 clean room has been built and an optical bench and other components have been procured and installed in this facility. Design work is currently in progress on adaptive optics systems, which will undergo laboratory testing and validation using this room. Additionally, as part of a new infrastructure development plan, the laboratory is expected to get additional floor space of about 275 sq.m , which is envisaged to be an assembly laboratory for large instrumentation.

In August 2009, an MoU was signed between IUCAA and Caltech Optical Observatories for an equal partnership for developing an adaptive optics system suitable for 1- 3 m class telescopes. This project (RoboAO) envisages the development, deployment and demonstration of a low-cost, autonomous, Rayleigh laser guide star (LGS) adaptive optics (AO) system and science instrument on the fully robotic 60 inch telescope (P60) at Palomar Observatory. By providing high-angular resolution and high-sensitivity visible and near-infrared science with unprecedented observing efficiency, RoboAO will enable exploration of science parameter spaces inaccessible to large diameter telescope AO systems. The approach will mitigate risk and cost via reuse of proven, well understood components and rigorously modularized and tested system control software. It is expected that when deployed on sky, RobAO will serve as an archetype for a new class of affordable AO system for 1-3 m telescopes, bringing the benefit of adaptive optics to the large community of moderate-diameter telescopes. Figure 30 shows components of RoboAO being set up and tested in the laboratory at Caltech. IUCAA is involved in the design and development of several components of subsystems like the laser guide star facility (launch optics, range gate), deformable mirror and tip/tilt mirrors (hardware and software drivers) etc.

A second MoU has been signed in February 2010, between IUCAA and the Department of Astronomy at the Univeristy of Wisconsin-Madison (UW-M), under which, IUCAA laboratory, will develop and supply the detector controller, data acquisition and data handling systems for the near-infrared arm of the Robert Stobie Spectrograph

Figure 31: A false colour image of the first propagation of the Robo-AO laser guide star from the Palomar 60 inch telescope

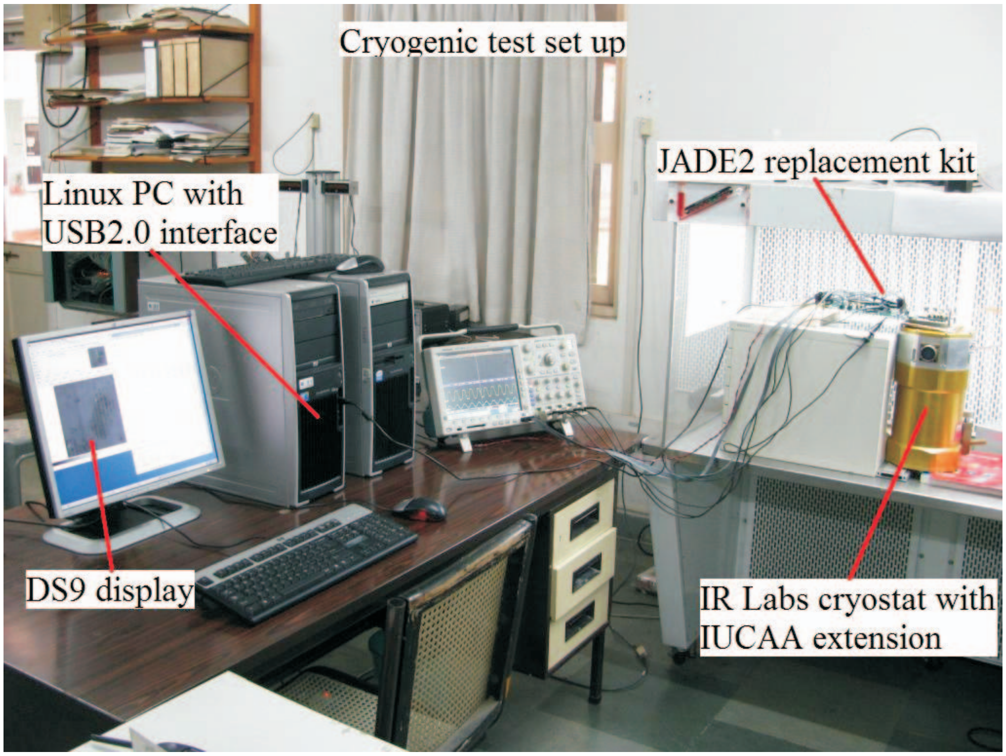


Figure 32: Test set up at IUCAA laboratory for FPGA-based SIDECAR controller for data acquisition from HAWAII detector.

(RSS-NIR) for the Southern African Large Telescope (SALT). RSS-NIR is currently being developed by UW-M under a contract with SALT. As part of this MoU, IUCAA will receive additional observing time on SALT.

This collaboration leverages on the next generation array controller (see last year's report) being developed in IUCAA's laboratory which has been conceived as a versatile system that can handle a wide variety of detectors used in astronomy (CCD, CMOS, HgCdTe) under a range of operational requirements. Figure 32 shows a prototype of this system under development and test in the laboratory in which a HAWAII-2RG ROIC with SIDECAR-ASIC is being controlled by an IUCAA controller board from a Linux PC.

The integrated backend instrument control system (TELICS) and the integrated power control system (both were just installed at the time of last year's report) have been working successfully, thus, enhancing the on-sky efficiency of the telescope. Another important milestone which has been achieved by the laboratory is the successful commissioning and perfomance verification of the optical fibre-fed integral field unit (FIFUI) on IUCAA telescope. This has been described in detail elsewhere in this report.

A substantial holding of routine and strategic spares has been built up for the IUCAA telescope and a spare management system has been put in place through a mammoth effort spanning well over a year. Contacts which were made with the Astrophysics Research Institute (ARI), Liverpool, UK, who operates the Liverpool telescope on La Palma, Spain, has been very useful in resolving some of the issues that occurred at the two observatories over the past year.

IFOSC's ageing EEV CCD was replaced with the a new E2V CCD and controller, which has relatively better performance. This detector has been in use at the observatory for several months now.

IUCAA and NCRA have been collaborating in developing a control and monitoring system (CMS) for observatories which will provide a frame work to exploit the commonalities in the control and operation requirements at astronomical observatories, irrespective of the wavelength of operation. The system will be developed through contract with a suitable professional software development firm. The approach envisages to asbtract the generic CMS requirements in a multi-layered state machine architecture and deal with the specific requirements of individual observatories through configuration tables and rule sets. It is also specified that the top level software should be decoupled from the driver level details of the underlying hardware to be controlled, thus allowing easy replacements and upgrades of hardware.

(4) IUCAA Girawali Observatory (IGO)

The telescope at IGO largely worked smoothly during this period. Nevertheless, there were two major episodes of telescope failure. One was related to the support of secondaty mirror and the other was related to the Cassegrain motor. Both the issues were timely resolved by the IUCAA laboratory team.

The CCD system working with the IFOSC at the telescope has been replaced with a new CCD system having a similar 2K x 2K E2V chip. The new system has been satisfactorily working since October 2009.

The primary mirror of the telescope was realuminised in December 2009 using the coating plant at IGO. The mirror reflectivity achieved was 88%. This has resulted in a gain of almost one magnitude in the sensitivity of the telescope from the May 2009 situation.

The list of publications involving IGO telescope and daily night logs have been made available through IGO web page.

The existing 100 KVA generator at IGO has been in use for many years. Also, due to erratic power supply by the state electricity board, the generator has been running more like a captive power source rather than as a backup power source. This resulted in urgent need to replace the generator. Therefore, a new 125 KVA generator was ordered and successfully installed in March 2010.

Road from Girawali village to the Observatory had become bad due to weathering. A major road carpeting work was undertaken and has been successfully completed by the estate department of IUCAA.

(5) Virtual Observatory India - The Next Generation (VOI-TNG)

The Virtual Observatory India - the Next Generation (VOI-TNG) project based at IUCAA ended in the last quarter, after being operational for four years, following the first VOI project. IUCAA took up the first project soon after the concept of Virtual Observatories (VO) was formalized some years ago, and VO projects were set up in several countries. The aim of the VO is to develop software systems for the management, analysis, visualization and mining of large volumes of astronomical data in various forms, and to make it possible for astronomers to easily access the data and the tools over the Internet. Large and small VO projects in various countries have contributed to developing standards and tools, and new astronomical discoveries are now being routinely made using VO products. The VOI project is unique, in that, it is a collaborations between IUCAA and a software company, Persistent Systems Ltd (PSL), with partial funding provided by the Ministry of Communications and Information Technology, Government of India.

Over the years, VOI has developed a number of tools, like VOPlot for data visualization, VOStat for the quick and yet sophisticated statistical analysis of astronomical data, and VOMosaic for making image cutouts from the SDSS and 2Mass surveys. VOI tools and programmes are widely used by the community of astronomers and developers, either in their stand-alone forms, or through the world wide web versions installed on various international astronomical data services.

In recent times, including the period of this report, VOI has been involved with developing data archives, and proposal management systems (PMS) for the Giant Metre Wave Radio Telescope (GMRT) and the IUCAA 2 m optical and infrared telescope. The archives provide easy access to data gathered by these telescopes, while the PMS are a very sophisticated tool for dealing with the complex process of calling for proposals for using telescope time, for judging the scientific merit and technical feasibility of the proposals, and allocating time to those proposal which are successful. The VO provides various tools for use in these systems, increasing greatly their efficacy, and making crucial insights available to their users. VOI is now working on an archival system for the Southern African Large Telescope (SALT) in which IUCAA is a partner, and has been approached by various other projects for help with similar developments.

After the end of the VOI-TNG project, IUCAA is maintaining VOI with its own funds, and work is continuing in collaboration with PSL, which provides several software engineers at various levels.

IUCAA RESOURCE CENTRES (IRCs)

(1) Cochin University of Science and Technology, Kochi (Coordinator : V. C. Kuriakose, Jt. Coordinator : T. Ramesh Babu)

The facilities at the IRC have been regularly used by M. Sc. and M. Phil. students, research scholars and teachers. Students and teachers from neighbouring colleges also use the library and computer facilities. Talks and seminars were held under the joint auspices of IRC and the Department of Physics. The IRC Library contains 56 books and internet connectivity. A number of research papers have been published using IRC facility. The thrust areas of research are : Physics of black holes, Observational astronomy, Nonlinear dynamics and Quantum optics. During this yea, there have been 7 publications in referred journals. Using the telescope given by IUCAA, we have introduced two experiments in Astrophysics for the M. Sc. students; the experiments are :

1. Determination of apparent magnitude of a star
2. Measurements of lunar topography

Talks / Seminars

M. Vivek, *Deep sky observations*, October.

Colloquia :

(a) September 19, 2009 at Physics Auditorium, CUSAT.

V. C. Kuriakose - *Horava-Lifshitz gravity*

Minu Joy - *Primordial perturbation spectrum*

Joe Jacob - *Extended radio emissions*

Moncy V. John - *Probability and complex quantum trajectories*

(b) February 20, 2010 at Physics Auditorium, SPAP, M. G. University.

Projects presentation by student participants of IUCAA – MGU Workshop on Galaxy Photometry

1. Rakhi R. (SPAP) *Primordial non-Gaussianity with a step in the second derivative of the potential*
2. Azad C. S. (SPAP) : *Star formation in BCD galaxies*
3. Marykutty James : (SPAP) : *X-ray binary system*
4. Mani K. C. (SPAP) : *Investigation of cosmological models*
5. Philip Thomas (St. Thomas College, Kozhencherry) : *Spectral analysis IRAS 18325-5926*
6. Sreeja and Sindhu (St. Thomas College, Kozhencherry) : *Cosmological hypothesis- a critical appraisal.*
7. Alaka and Anjumol K. (SPAP) : *Tidal fields of BCD galaxies*

V. C. Kuriakose : *Symmetries and broken symmetries*

Other activities :

Public Out-Reach Programmes

i. Telescope making and sky watching for the school children

During the workshop on Physics, Scope and awareness programme was held at the Department of Physics, CUSAT, during April 20-30, 2009. Arvind Paranjpye from IUCAA led the telescope making sessions along with the Research Students of Theory Division. Lectures were delivered on Astronomy, Astrophysics and related topics.

ii. Lectures, telescope making and sky watching programmes at Schools

The following schools in villages were visited for conducting telescope making and sky watching programmes for the benefit of the students. Lectures in general astronomy were also given. The programmes were conducted in Malayalam.

1. Govt. Higher Secondary School, Piravom, September 17, 2009.
2. Govt. Higher Secondary School, Poothrika, September 30, 2009.
3. St. Mary's Secondary School, Kaliyaar, December 7, 2009.
4. Govt. V. Higher Secondary School, Thirumaaradi, December 20, 2009.
5. St. Thomas Secondary School, Thudanganaadu, January 21, 2010.

6. Govt. Higher Secondary School, Thattakuzha, January 22, 2010.
7. St. Mary's Secondary School, Bharanangaanam, January 27, 2010.

iii. Lectures in Astronomy given by the Coordinator at other places.

1. Govt. Secondary School, Perumbavoor, July 20, 2009
2. Higher Secondary School, Vaniyamkulam, Shornnoor, September 19, 2009
3. Workshop on Astronomy for school teachers, Newman College, Thodupuzha, October 15, 2009
4. Christ College, Irinjalakuda, November, 7, 2009
5. Govt. Training College, Kozhikode, In-service course for school teachers, February 7, 2010.
6. Govt. Training College, Trivandrum, In-service course for school teachers, March 2010

iv. Solar eclipse of January 15, 2010

Arrangements were made in the department premises to view the solar eclipse of January 15, 2010. The 6" telescope given by IUCAA and other small telescopes available in the department were used to view the eclipse. In addition to the students and staff of the department, students and staff of other departments, students and teachers of neighbouring schools and public came to view the solar eclipse.

The research scholars of the Astronomy and Astrophysics group : Nijo Varghese, R. Tharanath, Saneesh Sebastian, Vivek M. and Bhavya B. have rendered valuable services in making the Public Outreach Programme a great success.

(2) North Bengal University, Siliguri (Coordinator : B. C. Paul)

The faculty members of the university and neighbouring colleges regularly use the facilities available at the IRC, Physics Department, NBU. Some of the students of the Physics Department used the IRC library facilities for doing their project works. Researchers from different universities visited the centre during this period. IRC has been organizing group discussions and seminars by the local resource persons regularly. Scientists from different institutes also delivered invited talks. IRC, NBU has organized Popular Lectures by eminent Astrophysicists and a Workshop on making Small Telescope for school students as IYA-2009 activities in the region.

***Talks* :**

(i) D. Bhattacharya : *Explosions in the cosmos*, May 22, 2009; (ii) D. Bhattacharya : *Astronomy in X-Rays*, May 23, 2009 ; (iii) Rizwan U. H. Ansari : *Introduction to DGP brane cosmology*, August 20, 2009; (iv) S. K. Modak *: Quantum tunneling and black hole entropy as a state function*, December 8, 2009; (v) S. Dana : *Chaos in electronic circuits*, March 25, 2010; (vi) P. Roy : Synchronization *: In nature and in coupled chaotic oscillators*, March 25, 2010.

***Visitors* :**

R. K. Jha (SMIT, Sikkim), Sayden Bhutia (SMIT, Sikkim), Rumki Deka (SMIT, Sikkim), S. S. Karmakar (Jalpaiguri), Rathin Sarma (Hojai College, Assam), R. Ansari (Univ. of Hyderabad), S.. K. Modak (S. N. Bose National Centre for Basic Sciences, Kolkata), P. S. Debnath (ABN Seal College, Coochbehar), A. Saha (Darjeeling Govt. College), P. K. Chattopadhyay (Alipurduar College, Jalpaiguri), D. Bhattacharya (IUCAA, Pune), A. Paranjpye (IUCAA, Pune), S. Dhurde, (IUCAA, Pune), S. K. Dana (Indian Institute of Chemical Biology, Kolkata), P. K. Roy (Presidency College, Kolkata), P. Haldar (Dinhata College, Coochbehar), S. Manna (Dinhata College, Coochbehar).

Other activities :

***Public Outreach* :**

1. **IYA Activity** : IUCAA Resource Centre, NBU, has organized a Workshop on making Small Telescope making for schoolstudents during May 29-30, 2009 at North Bengal Science Centre, Siliguri. There were participants from various schools from hills and foot hill areas of Darjeeling. A group was formed with two students and a teacher of a school and there were

23 such groups, who assembled telescopes. Two lectures on telescope and an other on spectroscopy were delivered by A. Paranjpye and Samir Dhurde of IUCAA, Pune respectively. The students observed the night sky with the telescope they made in the workshop and enjoyed the workshop enthusiastically. The telescopes were handed over to the teachers of the respective schools.

2. **B. C. Paul** had given the following popular lectures at at North Bengal Science Centre :
   (i) Homi Bhaba Birth Centenary on Septmber 30, 2009 : BHABA - *A total genius*
   (ii) DST Interactive Programme on February 16, 2010 : *Satellite communication a giant leap for mankind.*
   (iii) Resource Person for workshop on **Solar Eclipse** at Siliguri Girls' School, organized by PBVM on July 19, 2009.

Ph.D. Thesis : Two

1. *On cosmological models of the early universe* by Dilip Paul; Supervisor : B. C. Paul.
2. *Some recent issues in relativity and cosmology* by Saroj Nepal; Supervisor : S. K. Ghosal.

No. of Publications : 14

(3) Delhi University (Coordinator : T. R. Seshadri)

Talks :

(i) Bindu Rani (ARIES, Nainital) : *Blazars : Present state of knowledge and future perspectives.*
(ii) T. P. Singh (TIFR, Mumbai) : *Is linear quantum theory exact or approximate?*
(iii) Nidhi Joshi (CTP, Jamia Millia Islamia, New Delhi) : *Bipolar harmonic encoding of CMB correlation patterns.*
(iv) Nisha Katyal (IUCAA, Pune) : *Interstellar dust modelling of extinction towards s ome IUE stars.*
(v) Madhavan Varadharajan (RRI, Bangalore) : *Loop quantum cosmology.*

Visitors :

Nisha Katyal (IUCAA, Pune), Bindu Rani (ARIES, Nainital), T. P. Singh (TIFR, Mumbai), and M. Varadharajan (RRI, Bangalore).

Public Lecture :

Ajit Kembhavi (IUCAA, Pune) : *The new planets : Worlds outside the solar system?*

Lecture Series :

Series of 3 lectures were given by T. R. Seshadri for undergraduate students. These were held at two colleges : Miranda House and St. Stephen's of University of Delhi.
The topics of the lectures were : (i) Physics of stars (ii) Physics of galaxies and (iii) Physics of the expanding universe.

Other Activities :

Astronomy Exhibition : An exhibition of astronomy photographs entitled, "Surprises of the Cosmos" was held from February 9 to March 3, 2010 in collaboration with Centre for Science Education and Communication (University of Delhi), Instituto Cervantes, New Delhi, and Department of Physics and Astrophysics.

Workshop :

A workshop on 'Physics of Stars' was held at Sri Venkateswara College, University of Delhi and co-organised by IRC, Delhi during October 23-25, 2009. It was aimed at undergraduate students to give them exposure to astrophysics and catch bright and motivated young students and inspire them towards research. Over 30 students from I. I. T. Delhi, D. C. E. and more than 10 different University of Delhi colleges plus more than 30 students from Sri Venkateswara College participated in this workshop. There were nine talks on various aspects of stellar astrophysics by H. P. Singh, N. Panchapakesan, Patrick Dasgupta, Ashok Goyal, T. R. Seshadri (all from Universityof Delhi) and Pranjal Trivedi (Sri Venkateswara College). In addition, a tutorial session and night time sky watch observation through a telescope was conducted at the Department of Physics, University of Delhi, North Campus.

(4) Pt. Ravishankar Shukla University, Raipur (Coordinator : S. K. Pandey)

The faculty members, and research scholars in the university, as well as visitors from other universities/ colleges in this region have made use of the facilities (internet, library, etc.) provided by IUCAA at the centre in strengthening their research activities. Some of the important activities of the centre during the year are listed below.

Research activities :

D. K. Chakraborty and his research students ahve continued their work on the projected properties of a family of triaxial mass models. They have extended their work on the mass models with central cusp to investigate the effect of the inclusion of high order residuals on intrinsic shapes of elliptical galaxies.

S. K. Pandey has been involved in an ongoing collaborative research programme with A. K. Kembhavi on "Multiwavelength photometric study of dusty early-type galaxies", for which the 2 m IUCAA telescope at IGO was used to obtain deep imaging in H-alpha band. Also the programme of studying faint outermost region of the galaxies from the Large Format Camera (LFC) field was continued during the year. A paper entitled "Isophotal shapes of early-type galaxies to very faint isophotal levels" reporting their findings has been under preparation for publication. This is a collaborative research programme involving Laxmikant Chawae, A. K. Kembhavi, Russell Cannon, Ashish Mahabal, and S. K. Pandey and constitutes the thesis work of Chaware.

Nand Kumar Chakradhari, Lecturer in the department, has been actively involved with his research work on "Short period variability in chemically peculiar stars".

Research project :

A research project entitled "Photometric and spectroscopic studies of galaxies in deep survey fields" approved by ISRO, Banagalore under RESPOND programme, with S. K. Pandey as PI and A. K. Kembhavi as Co-PI enters into its second year. The total cost of the project is Rs 18. 24 lakhs. Laxmikant Chaware as SRF and Samridhi Kulkarni as JRF have been working under this project.

Poster/paper Presentation :

1. A poster entitled "*Multiband photometric study of dusty early type galaxies*", Samridhi Kulkarni, Laxmikant Chaware, D. K. Sahu, N. K. Chakradhari, S. K. Pandey, won the 3rd prize at the 16th *National Space Science Symposium* held at Saurastra University, Rajkot, during February 24 - 27, 2010.
2. A paper entitled " The Nainital-Cape survey. III. A search for pulsational variability in chemically peculiar stars" Joshi S., Mary D. L., Chakradhari N. K., Tiwari S. K., Billaudc, publisher in A&A, 2009.
3. A paper entitled "Time resolved photometric and spectroscopic analysis of the luminous Ap star HD103498", Joshi, S., Ryabchikova, T., Kochukhov, O., Sachkov, M., Tiwari, S. K., Chakradhari, N. K., published in MNRAS, 2010.

Public Lectures :

S. K. Pandey, "*General astronomy*", State Council of Education, Research and Training (SCERT), Raipur, January 5, 2010.

S. K. Pandey, "*Stars : Their structure and evolution*" during the workshop organized at Govt. Girls College, Durg, February 16, 2010.

N. K. Chakradhari, "*Telescopes and multiwavelenth universe*" in Teachers Training Programme at SCERT, Raipur and at Govt. College, Dongargarh.

***Visitors* :**

M. K. Patil (SRTM University, Nanded), Vijay Mohan (IUCAA, Pune), Arvind Paranjpye (IUCAA, Pune), Ajit Kembhavi, (IUCAA, Pune), Gulab Dewangan (IUCAA, Pune), Ashok Ambastha (PRL, Ahmedabad), D. K. Sahu (IIA, Bangalore), Russell Cannon (AAO, Australia), Sudhanshu Barway (SAAO, South Africa), Arvind Ranade (DST, New Delhi) and D. K. Shrivastava (VECC, Kolkata).

Other Activities :

Workshop :

(i) "Telescope Making Workshop" was conducted in association with IUCAA, Pune and IRC, Raipur for school teachers and students at SCERT, Raipur, during January 4 - 6, 2010.

(ii) A "Three day State Level Camp for College Students" was organized at the IRC, Raipur, during January 11-13, 2010, funded by COST through DST, New Delhi. Eminent scientists from all over India delivered lectures and also events like Poster competition and Quiz competition were organized during the workshop. The winners of the respective events were awarded at the closing ceremony.

Sky gazing programme :

Some of the main sky gazing events during the year were :

22 July 2009 – Total Solar Eclipse.

15 Jan. 2010 – Partial Solar Eclipse.

Along with these events, the regular sky gazing programme for students of the department/ uUniversity, students from local schools/colleges, as well as for the general public were organized during January 4 - 6, 2010 and January 11-13, 2010 (during the Three day State Level Camp for College Students), April 22, 2010 (at SCERT, Raipur).

Student's seminar :

M. Sc., and M. Phil. students of the department have made use of the IRC facilities for the preparation of weekly seminars organized by the department.

TV / Radio Programmes :

Under the Science popularization programme, faculties and research scholars of the department participated in the TV, as well as radio programmes in the local radio stations.

Data Centre : IUCAA is establishing a data centre at the IRC, Raipur. It is likely to be ready by June 2010.

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 2010

Sr. No.	FUNDS & LIABILITIES	Schedule No.	31.03.2010 Rs.
1	Trust Fund / Corpus	6	**3,33,76,194**
2	Grant-In-Aid from UGC	7	**93,48,12,079**
3	Other Project Grants	8	**2,86,33,146**
4	Projects and Other Payable	9	**14,78,031**
5	Current Liabilities	10 & 10A	**39,43,026**
6	Income and Expenditure a/c	14	**13,94,072**
	Total		**1,00,36,36,548**

Sr. No.	ASSETS & PROPERTIES	Schedule No.	31.03.2010 Rs.
1	Fixed Assets (At cost)	11	**73,47,69,979**
2	Investments / Deposits	12	**22,73,16,733**
3	Project & Other Receivables	13	**20,80,724**
4	Current Assets -	13	
	a) Cash, Bank balances & Revenue Stamps		**21,30,652**
	b) Loans and Advances	13A	**53,71,922**
	c) Deposits		**13,02,619**
	d) Prepaid Expenses		**65,02,359**
	e) SALT (Southern African Large Telescope) Operations Levy		**1,84,95,133**
	f) Advance to Suppliers	13B	**56,66,427**
	Total		**1,00,36,36,548**

For Inter-University Centre for Astronomy & Astrophysics

As per Report of even date
For Kirtane & Pandit
Chartered Accountants

N. V. Abhyankar
Admn.Officer (Accounts)

K. C. Nair
(Sr.Admn.Officer)

Parag Pansare
(Partner)
Membership No. 117309

Place : Pune
Date : 02.07.2010

Prof. A. K. Kembhavi
(Director/Trustee)

Chairperson
Governing Board